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# THE INSTITUTION OF PETROLEUM TECHNOLOGISTS

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## PERSONAL NOTES OF MEMBERS AND SPECIAL NOTICES.

*It is suggested that members send information regarding their movements to the Secretary, for insertion under this heading.*

Lieutenant J. H. BLAKISTON, R.N.R., is in Holland.

Mr. R. BROADHURST has left Ecuador and is in Miri.

Mr. C. BARRINGTON BROWN is in Peru.

Mr. W. E. D. COLE has left Persia and is in Iraq.

Mr. CHARLES DABELL is leaving for Argentina.

Mr. E. H. DOVE is home from Venezuela.

Mr. V. DVORKOVITZ is in California.

Mr. A. LLOYD EASTLAKE has joined the Engineering Staff of the Sinclair Oil Refining Co., East Chicago.

Mr. A. G. ENGELBACH is in New Jersey, U.S.A.

Mr. F. A. FLINN is in Mexico.

Mr. W. GRANT is home from Burma.

Mr. P. M. GRIFFITH has returned from Mexico.

Mr. F. R. S. HENSON has returned to Iraq.

Mr. A. W. IBBETT has returned from New York.

Mr. S. LISTER JAMES has returned from Trinidad and is in England.

Brig.-Gen. F. C. JENKINS is in Missouri, U.S.A.

Mr. D. GLYNN JONES has left Iraq and is in Persia.

Mr. M. KAMEN KAYE is now in Venezuela, engaged on Palæontologic work.

Mr. H. R. LOVELY is in Mexico.

Dr. W. R. MACFADYEN is home from British Somaliland.

Mr. J. L. MACLEOD is in Trinidad.

Mr. H. F. MOON is in Iraq.

Mr. ARTHUR MOORE has returned to Australia.

Mr. G. E. OWLES has returned to Peru.

Mr. E. W. H. PEEL is home from Persia.

Mr. R. R. RAKESTRAW is in California, U.S.A.

Mr. F. G. RAPPAPORT is returning to Venezuela.

Mr. D. P. REES has left Assam and is in Trinidad.

Mr. F. SAGER has returned from Italy.

Mr. G. SHEPHERD has been appointed State Geologist to the Republic of Ecuador.

Mr. D. SIMMONS has returned to Persia.

Mr. R. WOOD SMITH has left for Assam.

Mr. T. SPENCER is home from Rumania.

Mr. A. G. A. SUTTON has returned from Persia.

Mr. JAMES C. TEMPLETON is home from Venezuela.

Mr. H. J. THORNE has returned from Rumania.

Mr. E. R. TIDEY is home from Mexico.

Mr. D. S. TREBLE is now in Iraq.

Mr. C. J. WARD is in Texas, U.S.A.

Mr. J. W. WEITZ is home from Trinidad.

Mr. H. N. L. C. E. C. DE WILDE is in Holland.

Mr. W. D. WILLIAMS is home from Argentina.

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The Secretary would be glad to hear of the whereabouts of the following members:—C. A. BAUDUIN, A. E. O. COOKE, A. F. H. GEE, T. S. HARRINGTON, W. J. HARRIS, L. B. HOLLOWAY, A. F. C. PARKER, NAND LAL PASI, W. E. SHEPHERD, R. K. VAN SICKLE, and F. E. G. WATSON.

## OBITUARY.

### JOHN E. MARSHALL HALL.

It is with regret that we record the death of Mr. John E. Marshall Hall on July 13th, 1930, at the age of 70 years, after a long and painful illness.

Mr. Marshall Hall gained his Associateship of the Royal School of Mines at the age of 21, and after spending some time in the Rio Tinto Copper Mines, Spain, took up teaching and subsequently joined the staff of Colonel James for Army Coaching, and also with Mr. Woofram. Later he became a member of the travelling staff of the late Sir Boverton Redwood, and on his behalf carried out geological work in various parts of the world. During the Great War he relieved a younger man in a school in the North of England. After the war he again took up geological work, going abroad on several occasions for Messrs. Eastlake and Sutton. He eventually joined the staff of the Anglo-Persian Oil Company as Librarian, a post which he occupied until his failing health compelled him to retire.

Mr. Marshall was a good linguist, speaking French, German, Spanish, and a little Italian and Dutch. He joined the Institution in 1913 as an Original Associate Member, and transferred to full Member in 1915. He is survived by his widow, to whom we tender our condolences in her loss.

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## GEOLOGICAL SOCIETY OF LONDON.

The Council of the Geological Society of London announce that a sum of approximately £140 is available in the J. B. Tyrrell Fund, which was founded to further the knowledge of the geology of the Dominion of Canada, and invites applications from geologists who desire to carry out research in the Dominion of Canada. Applications must be received by the Secretaries, Geological Society, Burlington House, London, W. 1, not later than the second Wednesday in January next.

# THIRD (TRIENNIAL) EMPIRE MINING AND METALLURGICAL CONGRESS, SOUTH AFRICA, 1930.

The following papers were submitted by the Institution of Petroleum Technologists and read before the Third (Triennial) Empire Mining and Metallurgical Congress in South Africa :—

"Economics of the Petroleum Situation." By Sir Frederick W. Black K.C.B.

"The Torbanites of South Africa." By E. H. Cunningham Craig, B.A., F.R.S.E., F.G.S.

"The Gaseous Products of Shale Retorting—their Composition and Possible Utilisation." By Professor Alfred W. Nash, M.Sc., F.C.S., M.I.Mech.E.

## Economics of the Petroleum Situation.

By Sir Frederick W. Black, K.C.B. (Past President).

### Part I.—General Review.

*Note.*—Part II. deals with Statistics and Part III. with the Petroleum situation of South Africa in particular.

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The position in which "supply" stands in relation to "demand" in the case of petroleum, including crude oil and the whole range of finished products—*e.g.*, motor spirits, lighting and burning oils, lubricating and fuel oils, paraffin wax, etc.—comes under constant and world-wide review in the many technical journals which concern themselves with the oil industry. In the United States, in Great Britain and elsewhere the commercial technical Press (*e.g.*, the *Gas and Oil Journal of Tulsa, Oklahoma, U.S.A.*, *Oil News*, *Petroleum World* and *Petroleum Times*, etc., in England, to mention only a very few out of many representative papers), and also Government Bureaux of Trade, etc. (*e.g.*, in Britain the Imperial Institute, Mineral Statistics), publish statistics, progress reports and marketing news. The Petroleum Institute in the U.S.A. and the Institution of Petroleum Technologists in Great Britain publish, according to their respective functions, papers and essays on technical developments in the production, refining and distribution of oils. It is, of course, obvious that the business men who direct the great oil companies of the world must make almost a day-to-day study of data and statistics relating to their industry. The survey that is probably also made in every oil producing or oil consuming country by statesmen, economists,

oil consumers and others, will be of a more general character and less frequent, but will, nevertheless, be comprehensive and conducted at fairly frequent intervals. The oil output of various parts of the world; its fluctuating tendencies; the outputs of refineries; the movements of oil prices; exports from producing countries; imports into consuming countries; variations in countries of origin of supplies to particular countries; variations in percentage of use of different descriptions of oil; new adaptations of mechanisms, transport, motor ships, aircraft, etc., affecting oil consumption; progress with new processes of extraction of oil from shale and coal and utilization of by-products; all these and numerous other details, interesting from the point of view of Government Trade Bureaux, Technical Societies, the general community, the consumer, the manufacturer, the engineer, etc., should be everywhere the subject of systematic collection of statistics, and of an economic review of their tendencies as a basis for any necessary action, industrial or otherwise. In 1927 the writer of this paper, following the lead given in the valuable "Resources of Fuel of the Empire Survey" (1924, published by Ernest Benn, Ltd., London), presented an outline sketch of the economic situation of oil in British dominions for the second (Triennial) Empire Mining and Metallurgical Congress held in Canada. The general conclusions therein stated still hold good. In the U.S.A., where 70 per cent. of the world's oil supply is produced, an interesting study from the economic, no less than the purely business standpoint, is that of the variations in "stocks," which form as it were the barometric indications as to whether "demand" or "supply" is the more active factor over a given period. Stocks in U.S.A. may sometimes amount to a quantity equivalent to about six months of the world supply. The storage of large supplies in steel tanks or reservoirs is, however, a costly business, and, only to a limited extent, can "flush" production be "taken care of" in that way, in order to stabilise prices and refinery operations until a growing demand absorbs surplus supplies and again brings about a temporary equilibrium. A close examination of the statistics of "stocks" and of the fluctuations in the prices paid by refiners for "crude" oil (*i.e.*, if they purchase from independent producers), together with the market prices of motor spirit, lighting and fuel oils, etc., would enable a judgment to be formed as to how far production at any given period is meeting what can be called a "natural" requirement, as distinct from an "artificial" one more or less prematurely forced by exceptional low prices and commercial selling activity. An artificial demand, created partly perhaps at the expense of other fuels—*e.g.*, coal and coal products, tends to become permanent in whole or part and to

fall into the aggregate normal market requirement, which will probably have to be met eventually at higher prices unless exceptional increases of production continue to take place. Fluctuations of supply in relation to demand are amongst the special features of the oil industry which, by disturbance of prices, refinery operations and distribution arrangements, necessitate special consideration by the leaders of the oil industry of methods for the better and more uniform regulation of supplies to minimize fluctuations, and provide for the normal growth of demand at average or more or less stabilised prices. So far as the mechanical control of the flow of an oil-well is concerned, the modern oil engineer has solved the problem by means of powerful control valves. So far as the limiting of the number of wells is concerned, the oil geologist, though far from claiming or possessing infallibility, is well able to recommend, with but a reasonable percentage of errors, the proper number and spacing of wells necessary for the economical draining of a particular oil-pool or area. The reason or cause in many fields of offering surplus or excess supplies of crude oil to the refiners is the competition of "off-setting" wells that goes on in those cases where the royalty rights of surface owners lead to haphazard competitive drilling and flowing rather than to a scientific control of those operations. Where large areas are worked under unified control, the number of wells and the flow of each admit of regulation on a more scientific and economical basis for the adequate drainage of an area in such measure as may be needed to meet normal market demands. In the newer oilfields these conditions obtain not universally, but to a much larger extent than in most of the older oilfields—*e.g.*, of the United States of America and some other countries. This matter has been the subject of considerable discussion, especially in America. In that country in particular the matter of co-operative regulation of supply is to some extent complicated by legal questions as to the permissibility of agreements between various interests, especially those that operate in different States. These matters are mainly the domestic concern of the interests directly affected, but large surpluses of oil in one or more fields enter into the general competition of the world's oil market and affect world prices and distribution organisations generally. Methods of oil production are thus a matter of world-wide concern. The movement in the U.S.A. towards the better regulation of supplies has its ups and downs, and seems not to have reached any very definite stage at present. So far our remarks have been of a general character applicable to world-wide conditions, and we shall find if we peruse the reports of proceedings of conferences, etc., of oil men in any country, even in the United States of America, that whilst the national or local

conditions naturally receive specific attention, nevertheless their repercussions or influence on the world situation are always in the minds of those who deliver the principal addresses. We have before us at the moment a report of the extremely interesting and instructive proceedings of the American Petroleum Institute at Chicago in December, 1928. Putting aside, as not belonging to the economist's province, the many able papers of a technical and scientific nature, we shall find matter for brief comment on our own particular line of thought in the opening address of a Vice-President of the Institute, Mr. Axtell J. Byles. He set forth four propositions as "axiomatic," viz.:—(1) The oil business is a basic and essential industry, since petroleum and its products are indispensable to present-day social and economic life; (2) the oil industry, whilst not susceptible of being operated on a public utility basis, has, nevertheless, a profound obligation of public service; (3) oil business must be run profitably, but must avoid if possible alternating periods of over-production and threats of under supply—of feast in some branches and famine in others—without "co-operation" from within or control from without; and (4) the petroleum industry must attain "rationalisation." The much-worked words and the very essential realities that they stand for, viz., "co-operation," "rationalisation," and "stabilisation" are very much to the front, therefore, in oil as in other industries where excessive competition has proved to be neither an unmixed blessing nor economically sound. At the dinner of the Congress of the Institute, the Chairman of the Anglo-Persian Oil Company (Sir John Cadman) was the principal guest, and delivered a striking address on the economic problems of the oil industry. The concluding passage of his speech was as follows: "Remembering, indeed, that for oil as a universal element there are no real boundaries except those that are economic, let us not rest content till we have re-drawn the map of that one great oil country—the world." The same speaker had remarked a few sentences earlier that the world's oil problems "arise from the lack of invariable proximity, apparently ordained by Nature, as between the main consuming areas and the chief centres of supply, as well as the persistence with which in the United States itself demand forges ahead only to be overtaken by supply." Mr. Axtell Byles had clearly in mind some of the problems of rational control of production by agreement in order not to force a premature demand, to which we have already referred. The Chairman of the Anglo-Persian Oil Company would naturally be impressed by the advantages of readjusting market supplies so that new fields—*e.g.*, in Asia and elsewhere—should "take care" to a greater extent of the nearby or local markets, and save the expense of long haulage by tank steamers. Sir John

Cadman in his phrase, "no real boundaries except those that are economic," obviously takes cognizance of the fact that owing to possibly an insufficient local demand as well as variations in the quality of oil in different fields, the long haul is sometimes unavoidable—*e.g.*, the U.S.A. normally imports heavy fuel oils from Mexico and other countries, and sends out world-wide, motor spirit, lighting and lubricating oils made from superior grades of "crude." If, for example, the aviation services of, say, Europe call for the finest grades of motor spirit, the supplies will naturally come from whatever "crude oils" are best adapted to yield spirit of the desired quality with little regard to the geographical situation of the wells. Lighting and lubricating oils of special quality all the world over are often drawn from more distant sources of supply than local oilfields if the latter are not naturally rich in these particular "fractions." The speeches we have quoted were addressed to oil men, and their implications could have been readily comprehended. The audience, however, would have comprised men of varying experience and diversity of interests working under dissimilar conditions. Their "view-points" would not, therefore, have been absolutely identical. Moreover, at the gathering referred to, the speakers recognised that there will always be advocates of rapid exhaustion of fields for present advantage, who regard any disturbance of markets or meeting the needs of the future as matters of minor importance. This attitude would be found amongst oil producers and distributors who desire a maximum and immediate profit, and quite as much also amongst consumers who want low market prices here and now, and do not see far ahead enough to understand that even their own advantage might be better conserved by what Sir John Cadman called "stabilised" or average prices. Put concisely—there will always be in the oil trade amongst suppliers and consumers the "long view" taken by some and the "shorter view" taken by others. Amongst other factors which the consumer is likely to overlook is that when a surplus production has given him the advantage of a low price his Government may choose that moment for deciding that he is peculiarly favourably situated for paying extra taxation, and yielding part of his advantage as an oil consumer for the benefit of the revenue generally and other taxpayers' interests which Governments have to keep in mind. The consumer of oil, as of other staple products, is apt also to run after low prices in preference to high and uniform quality and good service, till experience puts him wise. Nevertheless, the consumer is the natural complement of the supplier, and the two have to get together in the long run, the one to satisfy and the other to be satisfied. In respect of quality there is necessarily a considerable measure of

co-operation between user or designer of engines and machines and the oil supplier as to specifications of essential qualities and necessary tests.

Also, the ordinary consumer's opinions on quality and performances with various grades are of value, and even complaints serve a good purpose since the large concerns especially investigate them with great care, notwithstanding the expert watchfulness exercised at every stage in the refinery. As a rule, it may be said that the big oil companies everywhere leave little to be desired in quality and service. It is usually on the subject of "price" that the consumer is vocal, as with other staples—*e.g.*, food, milk, rent and other daily needs. It would not be difficult to show by detailed statement of fact and figure, as, in fact, is often done in the oil journals, that there are few commodities which yield better to value of efficiency in use for price paid than oil products, whether motor spirit or lighting or lubricating or fuel oils. Every consumer, every user of a small car or motor cycle even may make his own calculations in this regard as to the advantage which he gets from his expenditure on oil as compared with other things. It would be idle to pretend that criticism of prices may not be valuable and wholesome in respect of any commodity. Obviously, such criticism is of value in proportion as it may be based upon knowledge of facts and conditions. Although a general acquaintance with the circumstances of the oil industry is on the increase, the comparatively recent development and the complexity and world-wide nature of operations in that trade render it more difficult for the average consumer of oil products to base his criticism on detailed knowledge and experience than in the case of older and more familiar staple industries and manufactures. It will take time, therefore, for the oil consumer to realise fully that whatever regulation of prices, etc., appears to be made or to exist, standard market prices in oil as in other commodities reach their level only as a matter of keen competition for the largest share of the market, and by that balancing of interests which Adam Smith used to call the "higgling of the market." Though "saturation" point has not yet been reached in the use of oil, it is true that the qualities which the market will absorb are very much affected by ruling prices. Oil production and distribution and the maintenance of quality of supplies have had to keep pace with the remarkable developments in the last thirty years in the use of oil engines brought about by the skill of inventors in the matter of internal-combustion engines and the courage of pioneer engineers, air pilots, etc. The air has been conquered, a journey round the world by air has been effected in about one quarter of the eighty days occupied by Jules Verne's hero; a voyage by air from England to India

has been accomplished within about one week; a speed on a straight course of 360 miles an hour has been attained by aircraft; and high powered automobiles have reached a speed twice that of express trains. Great increases have taken place in the use of oil in high-powered steamships and motor-engined vessels, and the world's motor vehicles now number some thirty millions. To keep the supply and quality of the vital fuel and lubricating materials up to these exacting requirements has necessitated on the part of the oil industry great commercial enterprise and high talent of direction combined with the fullest use of the scientific and technical talent of geologists, chemists and engineers. A ton of crude oil has been made to yield a much larger proportion of its volatile constituents by means of intensive distillations, and natural gases have been stripped of their gasoline contents to a far greater extent than heretofore. Wells are drilled far deeper with the aid of improved drilling equipment, and their "siting" has been more scientifically planned by the geologist and geophysicist. Distribution of oil products by tank, steamers, pipe-lines, tank waggons, pumps, etc., has been widely developed. Oil bunkering stations for ships are practically as widespread as for coal, allowing for less frequent bunkering with oil. We conclude our general survey by emphasising some of the special features of the oil industry—viz., the indefinite nature of knowledge as to the duration of supplies, and as to the extent to which oil consumption will spread with its many attendant advantages till saturation point is reached. We do not enter upon the rôle of the prophet as to how long oil supplies will last, nor as to what depths oil wells will yet be drilled. We believe on the basis of experience and research that the day of exhaustion or serious diminution is comparatively distant, and if shale and coal oil be also considered there will be no need for anxiety for many years to come. We introduce in Part II. tables of figures showing the world's production of oil, the production of British Dominions, and the requirements of Great Britain and South Africa. It is well known that the world production of oil has increased unequally but very roughly about 100 per cent. every ten years (in some decennial periods less and in some more). The production to-day is ten times what it was thirty years ago, and four times the figure of twenty years back. The market absorption of these quantities has been for new services which older fuels could either not have met at all or only with difficulty and at high cost, and partly the increased use of oil has been at the expense of coal and its products. If oil for all-round efficiency be taken as twice that of coal, the oil production of 1928 equals about 360,000,000 tons of coal, or something like 25 per cent. of the world's coal production. The "world production" table shows the countries of origin of

natural petroleum. The features in recent years have been the abnormal increase in U.S.A. in 1927—*e.g.*, in Oklahoma and California. Of the other countries, Mexico has declined, but Venezuela and South America generally, and the Persian, Rumanian, Russian, Trinidad and Sarawak fields have advanced.

The "British Dominions" production increases steadily, in Trinidad in particular, but remains only a small fraction, some 2 per cent., of what those Dominions as a whole require. By far the greater part of the requirement of Great Britain and all British Dominions overseas has, therefore, to be met by import from U.S.A., Dutch East Indies, Persia and other oilfields. A feature of special note is the way in which new oil refineries have been established to deal either with local "inside" oil, as in South America, or mainly with imported "crude," as in Great Britain, France, Germany and Australia. This policy seems likely to be developed still further as time goes on wherever the requirements of a particular country are sufficient to "take care" of the products of a local refinery.

## PART II.—STATISTICS.

TABLE No. 1.—World Production of Petroleum, 1927-1929.

| Producing Country. | Thousands of Tons (*i.e.* "Long" Tons). 1927. | 1928. | 1929 (Estimated) |
|---|---|---|---|
| U.S.A. .. .. | 121,774 | 121,941 | 131,500 |
| Venezuela .. .. | 9,019 | 15,667 | 20,200 |
| Russia .. .. | 10,697 | 11,768 | 12,800 |
| Mexico .. .. | 9,570 | 7,485 | 6,200 |
| Persia .. .. | 5,241 | 5,742 | 5,500 |
| Rumania .. .. | 3,661 | 4,269 | 4,400 |
| Dutch East Indies .. | 3,448 | 3,971 | 4,350 |
| Colombia .. .. | 2,113 | 2,802 | 2,850 |
| Peru .. .. | 1,316 | 1,597 | 1,700 |
| Argentine .. .. | 1,240 | 1,329 | 1,450 |
| India .. .. | 1,138 | 1,200 | 1,100 |
| Trinidad .. .. | 739 | 1,062 | 1,200 |
| Sarawak .. .. | 712 | 751 | 670 |
| Poland .. .. | 723 | 737 | 670 |
| Egypt .. .. | 183 | 268 | 280 |
| Japan .. .. | 233 | 247 | 250 |
| Ecuador .. .. | 76 | 154 | 165 |
| Germany .. .. | 97 | 98 | 95 |
| Canada .. .. | 69 | 76 | 122 |
| Iraq .. .. | — | 87 | 89 |
| Others .. .. | 192 | 175 | 170 |
| Total .. .. | 172,231 | 181,426 | 195,861 |

This statement was prepared in August, 1929, and the 1929 figure is, therefore, only a very rough estimate based on the rate

of progress of a few months of the year. Later production may vary up or down, and the complete figure for 1929 will no doubt be available when Congress meets in March, 1930.

TABLE No. 2.—British Dominions Oil Production, 1927-1929.

| | 1927 | 1928 | 1929 (Estimated.) |
|---|---|---|---|
| | Long Tons. | | |
| United Kingdom* .. | 166,480 | 166,300 | 166,800 |
| Canada .. .. | 59,000 | 76,000 | 122,000 |
| Trinidad .. .. | 739,000 | 1,062,000 | 1,200,000 |
| India .. .. | 1,138,000 | 1,200,000 | 1,100,000 |
| Sarawak .. .. | 712,000 | 751,000 | 770,000 |
| Total .. .. | 2,814,480 | 3,255,300 | 3,358,800 |

* Scottish Shale and one small natural oil well.

TABLE No. 3.—Imports of Oil into the United Kingdom in 1927-1928.

Imports into the United Kingdom are about three times greater than they were ten years ago. The total import in 1928 was about 7,500,000 tons. The imports, stated in gallons, into the United Kingdom of the principal descriptions were as follows in 1928 and 1927; the value is also shown:—

| | Gallons. | | Value in £ Sterling. | |
|---|---|---|---|---|
| | 1928. | 1927. | 1928. | 1927. |
| Lighting Oil .. | 190,604,204 | 214,084,229 | 3,552,881 | 4,590,077 |
| Lubricating Oil .. | 104,954,831 | 91,592,666 | 4,798,134 | 4,705,562 |
| Motor Spirit .. | 730,959,481 | 538,216,001 | 18,157,890 | 16,259,023 |
| Gas Oil .. .. | 117,900,608 | 96,008,020 | 1,632,495 | 1,690,805 |
| Fuel Oil .. .. | 451,302,376 | 439,421,056 | 4,803,311 | 6,194,386 |
| Crude Oil (for refining in U.K.) .. | 503,140,284 | 663,810,033 | 5,946,568 | 9,627,666 |
| Other Sorts .. | 13,798,888 | 6,998,318 | 362,324 | 257,434 |
| Total .. | 2,112,760,672 | 2,051,130,323 | 39,253,603 | 43,314,953 |

NOTE.—There was an export of oils from the United Kingdom in 1928 of 123,223,644 gallons, valued at £3,021,768.

TABLE No. 4.—Imports of Petroleum Oil into the Union of South Africa during 1928, Showing Country of Origin.

| From— | Oil Fuel. Gallons. |
|---|---|
| Dutch East Indies and Holland .. .. .. .. .. | 6,617,504 |
| Persia .. .. .. .. .. .. .. .. .. | 4,859,255 |
| U.S.A. .. .. .. .. .. .. .. .. | 2,205 |
| Great Britain .. .. .. .. .. .. .. .. | 1,948 |
| Germany and Denmark .. .. .. .. .. .. | 518 |
| Total .. .. .. .. .. .. .. .. | 11,481,430 |

| Lubricating Oil. | Gallons. |
|---|---|
| U.S.A. | 4,011,496 |
| Great Britain | 591,586 |
| Dutch East Indies and Holland | 125,624 |
| Venezuela | 60,932 |
| Russia | 47,771 |
| Germany | 19,235 |
| Greece | 11,470 |
| Belgium | 5,555 |
| India | 2,841 |
| Straits Settlements and Hong Kong | 1,280 |
| Portuguese East Africa, Egypt and other countries | 2,557 |
| Total | 4,880,347 |

| Lighting and Burning Oil. | |
|---|---|
| U.S.A. | 12,199,524 |
| Persia | 983,901 |
| Dutch East Indies | 864,949 |
| British East Indies | 40,770 |
| Russia | 17,600 |
| Great Britain | 7,870 |
| Straits Settlements | 6,339 |
| Norway | 533 |
| Total | 14,121,486 |

| Motor Spirits (Gasoline, Petrol, etc.). | |
|---|---|
| U.S.A. | 29,478,824 |
| Dutch East Indies and Holland | 17,558,757 |
| Russia | 2,064,387 |
| Great Britain | 2,997 |
| Sweden, Portuguese East Africa, etc. | 1,846 |
| Total | 49,106,811 |

*Note.*—The above figures do not include the imports into Rhodesia (North and South), and are exclusive also of paraffin wax, grease, etc. Bringing together the total of the four groups as above and comparing them with approximate imports for 1913—*i.e.*, the year before the War, we get the following :—

IMPORTS INTO SOUTH AFRICA.

| | 1928. Gallons. | 1913. Gallons. |
|---|---|---|
| Oil Fuel | 11,481,430 | 158,483 |
| Lubricating Oils | 4,880,347 | 2,500,000 (Approx.) |
| Lighting Oils | 14,121,486 | 10,229,076 |
| Motor Spirits | 49,106,811 | 4,248,233 |
| Grand Total of Petroleum Oils Imported | 79,590,074 | 17,177,792 |

The significance of these figures lies first in the fact that in fifteen years South Africa's petroleum requirement has increased more than 4½ times. Oil fuel (largely for "bunkering" ships) and motor spirits show by far the larger percentages of increase, but the increase in lighting and lubricating oils, though far less, is still not negligible. As regards countries of origin, U.S.A. still leads the way, except in oil fuel. In recent years Persia and Russia have come into the South African markets. Some further observations under this head are made in Part III. of this paper. In tonnage (very approximately and without calculating specific gravities exactly in each case) South Africa's import of all petroleum products in 1928 may be taken at less than 300,000 tons, a comparatively modest fraction of the world's total production of crude oil—of upwards of 180,000,000 tons. Great Britain's annual oil requirements, as shown above, as met (except to a small extent) by import, is about 7,500,000 tons.

## Part III.—Notes on the Position of South Africa in Relation to Petroleum Supply.

The writer of this paper desires to express his thanks to the High Commissioner for South Africa, and to Mr. Dimond of the Trade section in particular, for the opportunity of perusing several useful books and reports—including "South Africa and Science (1929)," prepared for the British Association's recent meeting; *S.A. Journal of Industries*, October, 1917 (paper by Dr. Wagner and Dr. Ing); the same journal, July, 1923, for Major Trevor's survey of "Oil Yielding Rocks, S.A."; "The Prospects of an Oil-shale Industry in the Union," being a report by an Oil Fuel Committee, "issued by authority of the Minister of Mines and Industries," 1925; and, finally, the particularly valuable and comprehensive "Memorandum on the Development of an Oil Industry within the Union," by Mr. F. Meyer, Chemical Engineer of the Board of Trade and Industries, approved by that Board on September 7th, 1927, and printed by *Cape Times, Ltd.*, 1928. The present writer is unaware of what statistical and other information of this nature will be prepared in South Africa for the use of the Mining Congress of 1930, but he would refer those interested to Mr. Meyer's paper. The present writer in August, 1929, has had before him the import figures up to the end of 1928 (quoted above in Part II.) from the Customs Returns which he inspected in the High Commissioner's Office. It is of interest to note that American publications (see *e.g.*, the pamphlet "International Trade in Petroleum and its Products," U.S.A. Department of Commerce, Trade promotion series No. 80, 1929) take cognizance of all such data, as is the case with the British "Imperial Mineral Resources Bureau." In a

"World Oil Map," published on December 27th, 1928, in the U.S.A. *Oil and Gas Journal* (Tulsa, Oklahoma), the potentialities of Africa (except Egypt) as an oil producing-country are shown as somewhat indefinite. Possibilities are indicated in Madagascar, Nigeria, etc. The tropical regions of Africa, Western Africa perhaps in particular, are likely to provide to some small extent various vegetable materials from which "power alcohol" may be made which can possibly be used to best advantage mixed with ordinary motor spirit or with benzol (a coal product); there is a useful paper on this subject by Dr. Ormandy included in the *Empire Fuel Review* (1924), already referred to in Part I. of this paper.

It is interesting to note that South Africa's growing petroleum requirement has enabled her to draw upon new fields of supply—*e.g.*, Persia for fuel oil for ships, etc.—while she continues to rely upon her older established sources of supply for part of her requirements of motor spirit and heavy fuel from the Dutch East Indies, and for part of her motor spirit and almost the whole of her lighting and lubricating oils from the U.S.A. India has a share also in South Africa's trade—*e.g.*, in paraffin wax for candles. The Union of South Africa having at present little or no local oil production either natural or from shale or coal, her requirements are met by import, as is the case with nearly every other British Dominion. In Great Britain there is a shale oil industry and oil refineries have been set up which deal principally with imported crude oil from Persia, etc. Australia has shale oil potentialities, but the oil refinery erected in the Commonwealth in recent years by the Government in co-operation with the Anglo-Persian Oil Company, deals at present with imported Persian oil. South Africa, according to the reports above alluded to and an earlier one (1913) by Mr. Cunningham Craig, has shale oil potentialities in the Transvaal and in Natal, only partly explored, apparently, and not in any way commercially developed at present. In some of the reports above mentioned recommendations have been made to the Union Government in favour of a subsidized shale-oil industry. As a matter of pure economics, apart from policy, it is of course well understood that shale and coal-oil production only enter the market economically in active competition with imported natural petroleum when the prices of the products from either source are at about the same level or yield the same aggregate profit, taking all the products into consideration. The shale and coal-oil production is handicapped by expenses of mining and retorting to win the "crude oil." Such expenses may, and probably will, exceed the cost of sinking of wells for natural petroleum. The home product, on the other hand, has an advantage in the

matter of saving overseas transport charges and to some extent of inland carriage according to the situation of the industry in relation to the main centres of consumption. Natural petroleum also, as time goes on, may or may not suffer increasing disability of higher costs in the sinking of far deeper wells. This has already occurred, but is at present offset by the value of the increased production of motor spirit, etc. In some cases, dependent on the quality and composition of the various extractable elements in shales, there may be by-products, such as wax and ammonia, which may help out the total realised price per ton of products. In the case of oil from coal, many considerations arise affecting cost, viz., as to type of process applicable, *e.g.*, low temperature carbonisation (or distillation), hydrogenation, etc., also the question of the market for any solid or gaseous products, etc. Allusion has been made more than once in this paper to the necessity of using superior grades of oil products for certain purposes. Obviously, therefore, in any consideration of the question of a home industry it will be necessary to weigh up very carefully after extensive experiment to determine the possiblities of producing high grades of motor spirit for aviation, etc., and also special descriptions or types of lubricants and lighting oils which are now obtained economically and efficiently from particular descriptions of crude oil, etc., rich in those particular fractions. At the recent meeting of the British Association in South Africa, Sir Thomas Holland (President) said: "Everyone here must agree on two things, viz., our desire and even hope for international peace; and consequently the necessity of surveying the mineral situation as developments in technological science occur that change the configuration of the economic world."

No cut and dried dogma can therefore be applied to last for all time. The oil situation, like every other business and economic proposition, must be vigilantly and frequently reviewed with an eye on circumstances that never for long remain unchanged. If we need evidence of the changes in motor developments with which oil products must keep pace in quality and quantity, we have only to look around us, to pick up our newspaper or, on special occasions, to switch on the broadcasting receiver. At the time of writing this paper (end of August and beginning of September, 1929) the writer has interrupted his work to listen to the broadcasting first of all of speakers from New York and New Jersey (August 29th, 1929), relating in great detail the arrival of the "Graf Zeppelin" German airship on completion of a voyage round the world by air in just over 21 days, with actual flying time of 12 days only. The next notable achievement was the setting up of fresh world records for speed of air craft in the Schneider Cup

race in the air over the channel that separates the Isle of Wight from the mainland of England. A speed of 332 miles per hour was attained on two seven-mile laps of a "lozenge" shaped course with two acute angle turns. The equivalent in a straight run is probably upwards of 360 miles per hour, as was shown by actual straight runs of about that speed a few days later. The Press, speaking in terms of high praise of the courage of the pilots and the skill of the designers and engineers, has drawn attention to the "team-work" involved in the co-operation of flying-men with engine and craft designers and builders. This includes also the oil industry. It is noteworthy that in the Schneider Cup race the only defects that were developed were in two of the machines, not of the latest type, used by the Italians, viz., the "exhaust" in the one case and an oil-feed pipe in the other. It was mentioned in connection with the race for the Schneider Cup that the motor spirit expenditure was at the rate of about 100 gallons per hour for each machine. The development of high speed air travel thus obviously involves a large quantitative expenditure as well as high quality of supplies.

## The Torbanites of South Africa.

By E. H. Cunningham Craig, B.A., F.R.S.E., F.G.S. (Member).

### I.—Introductory.

It was during an investigation in 1913 of the petroleum possibilities in South Africa, undertaken for the Union Government, that the writer first encountered the torbanites. They were then known as "oil-shales," and some deposits certainly showed a superficial resemblance to oil-shale: it was not until certain specimens were cut for microscopic examination that it was proved that their matrix is carbonaceous and not argillaceous, and that they are true torbanites, occasionally of great richness.

Examination of further specimens, sent specially from South Africa, showed that the distribution of torbanitic beds is much wider than had been previously supposed, and that other seams classed rightly as cannel coal have also a distinct torbanitic development.

These discoveries were afterwards followed up by extensive prospecting, with the result that at least two districts where torbanites occur are now fairly well known.

So far as the writer is aware, the torbanites are confined entirely to the Transvaal, though at least one seam approaches closely to the Natal border: as outcrops are frequently obscured, it requires

extensive boring, with cores taken continuously, to determine the areas within which such seams occur, and much ground remains unprospected.

## II.—Geological Conditions, etc.

The torbanite seams occur in the lower part of the coal measure series of the Karroo beds, just as in Australia they appear in strata of much the same age. Owing to the overlap of the Karroo formation upon an irregular surface of older rocks, as we proceed northwards into the Transvaal, the lower divisons of the Karroo are frequently absent, the thickness of coal measure is often comparatively small, and correlation between different localities is not always easy or possible.

The formation is, as a rule, almost exactly horizontal, and does not appear to be much affected by faulting. Intrusions of dolerite, chiefly as sills, are frequent.

The only areas where systematic study of torbanites has been undertaken are the Ermelo and Wakkerstroom districts. In each of these numerous shallow borings have been made, while mines and adits driven into the hillsides have furnished additional evidence.

It is unnecessary to repeat the estimates of available tonnage of torbanite that have been published with regard to these two districts; they are at the best only estimates, and probably much more boring would be necessary before reliable data as to tonnage could be put on record.

One of the difficulties is that torbanites, being a special development of cannel coal, vary greatly in thickness, often dying out very rapidly. As a general rule there is a definite basin towards the centre of which the torbanite seam attains a maximum thickness, while it thins out in all directions, but may appear again at the same horizon some distance away. Torbanites invariably occur in composite seams, always associated with coal, and frequently with blackband ironstones, or with nodules of ironstone in the canneloid deposit.

Variations in quality of the material are not infrequent, and this has been noticed specially in South Africa, accounting for the different results of retorting specimens from the same seam from different localities. There are two causes for such variation in quality, the first being inherent and the other to some extent accidental. The first is due to the percentage of gels in the carbonaceous matrix varying. Seventy to eighty per cent. of gels is not infrequent in the best Transvaal torbanites, but when the seam is traced for a distance, this percentage may be found to fall off till the seam may pass into a more normal cannel coal with only a

small percentage of gels, possibly less than ten. The other cause of variation in quality is the natural degeneration to which the gels are subject. When the gels, as seen under the microscope, are of a pale yellow colour, not mottled or clouded, the yield of oil *ceteris paribus* is always good, and the oil is light and of high quality, but when the colour is dark yellow or even red-brown, or a mottling with dark brown is observed, the yield of oil is lower and the oil heavy and waxy. This degeneration takes place naturally with time or with rise of temperature, and can, as the writer has proved, be produced artificially. In South Africa proximity to a dolerite intrusion, either dyke or sill, affects the gels very distinctly, giving them a dark red-brown colour and a mottled appearance. In one case at Kijkvorshfontein, a part of the torbanite seam is so much affected that the material resembles a hard rubber and can only be sliced for microscopic examination with great difficulty: this occurence is within a few feet of a dolerite intrusion. The greater part of the seam is, however, much less affected.

These points are mentioned specially because the temperatures at which the best results in retorting are obtained depend upon the state of the gels in a torbanite. It has been demonstrated by the writer, that the degeneration of the gels is for all practical purposes a form of inspissation: that is to say a drying up of the oil content of the gels. In the case of a torbanite mined beneath the surface, it is obvious that little, if any, oxidation of the gels can take place, but a loss of light oils is certainly brought about by rises in temperature and through passage of time. Highly degenerated torbanites show these effects by yielding higher percentages of paraffin waxes in retorting, and less petrol and light oils. Extraction with solvents, which is really a more certain test, since the conditions can be more accurately determined, confirms this conclusively. Now in the Transvaal the gels in the torbanite seams vary from the very freshest state, showing a very pale yellow colour under the microscope, to a profoundly deteriorated state of a dark brown and mottled appearance. These differences mean a lower yield of oil, possibly as much as 50 per cent. in quantity and also a great falling off in quality of the crude oil. The inspissated gels require much higher temperatures in retorting, with a consequent increase in cracking effect in the retorts, a greater production of incondensible gas, and the formation of a larger proportion of unsaturated compounds in the crude oil, provided that a fairly complete extraction of the oil is aimed at. It is an axiom in low temperature carbonisation that the temperature should be kept as low as possible compatible with a fairly complete extraction of oil. The higher the temperature, the greater the expense of operating the retorting plant and the lower the value of the petroleum products obtained. It follows that a

careful study of the raw material is necessary ; the same seam may give very different results in different localities, and entirely erroneous estimates of yield and quality of oil may be put forward unless a regular check on the state of the retortable material be kept. The simplest and least expensive method of keeping such a check is by microscopic examination of thin slides.

In the writer's knowledge, some quite inaccurate estimates of the yield of oil from the South African torbanite seams have been given ; this is possibly due to some extent to the methods that have been used for extracting the oil, but more likely portions of the seam that are not true torbanite have been mixed with the richer materials, and the total result given as the yield from a torbanite seam. Such estimates naturally throw an unfavourable light upon the prospects of a retorting industry.

At the best, a Transvaal torbanite of the richer class and in a good, fresh condition is not likely to yield much more than 90 gallons of oil per ton, but the oil will be of very good quality if obtained by a modern process at a really low temperature. The percentage of petrol will be high, and unsaturated hydrocarbons will be in much smaller proportion than in the case of oil-shales. There will be good percentages of kerosine also, and the higher boiling fraction will contain paraffin waxes of excellent quality.

Seams in a slightly deteriorated condition will yield from 50 to 70 gallons of rather heavier oil, while the slightly torbanitic cannels should yield up to 40 gallons, the oil being naturally more of a tarry nature.

One of the great advantages of the torbanite fields in South Africa is that mining costs will be low. The seams, as stated above, are all composite seams, except perhaps in the case of some of the cannels, so it should nearly always be possible to extract a seam, composed of coal and torbanite, that is thick enough for ordinary working methods. The coal is of good quality, and can be used for fuel in the retorting plant if there should be no local sale for it. Alternatively, the coal, which usually has a fairly high percentage of "volatile material," could be retorted with the torbanite, in which case the result would be a better extraction of oils and tars from the coal itself than would be obtained if it were retorted alone, but the resulting mixed crude oil would probably be much more expensive to refine than that obtained from torbanite alone. These are matters which can be studied experimentally, once the retorting industry has been started : they are only indicated here as a field for further research.

Many estimates have been made as to the financial results that may be expected from a torbanite retorting industry in South Africa, and the writer has studied these from various sources.

The basis of such calculations are (1) cost of mining, (2) cost of treatment by different retorting methods, (3) cost of refining the crude oil, (4) cost of packing, transport and selling the refined products, and (5) value of the saleable products. As regards (1) and (5), there is a fairly general agreement, but (2) and (3) vary considerably according to the method of retorting employed. The cost of refining will vary according to the quality of the crude oil, which in turn depends on the state of the raw material and the suitability of the retorting process. (4) can be ascertained without much difficulty.

Without going into details, it may be stated that the estimates submitted to the writer show profits varying between £1 and £2 per ton of torbanite. Possibly such estimates have been framed somewhat optimistically, upon the assumption that all the torbanite will be of the highest class. This, as pointed out above, cannot be counted on. But it may be pointed out that if these estimates of profit be halved, which is a very severe diminution, there will still be a handsome profit per ton of material, and this should suffice to make the development of a torbanite retorting industry highly attractive.

The figures, it must be said, are founded upon numerous retorting tests, and careful analysis of the crude oil.

## III.—Retorting Methods.

It is not considered desirable in a paper of this nature to deal with the working or the results obtained from any particular retort, nor to compare one process with another. Where there are many different processes, each with excellent and often exclusive features, it would be invidious to make any selection.

The writer, however, is in possession of various tests of South African and other torbanites by different methods, so a few general statements may be set down here for the guidance of those who may be considering the establishment of a retorting industry in South Africa.

In the first place, it has been abundantly proved that old-fashioned retorting methods will never give the best results with a rich torbanite. Good results, as compared with results from oil-shales, can certainly be obtained, but if a high quality of crude that will be inexpensive to refine is aimed at, special and modern processes must be employed. Vertical retorts, expensive to erect and with a small through-put for their size, need not be considered; they cannot give the results desired.

Attempts at complete extraction of all the oil and gas from a torbanite in one process are to be deprecated. Such attempts demand comparatively high temperatures, causing an undesirable amount

of cracking of the oil vapours, a loss in quantity of oil, especially of light oil, an excessive production of gas, and greater expense.

Internally heated retorts should also be avoided, whether the heating be done by inert gases, oil vapours, or steam. The cost of superheating steam to do retorting work is too high; and thus the advantages of using such a heating medium are discounted. Inert gases, on the other hand, do not convey a sufficient quantity of heat, as their specific heat is not high : therefore a very large volume of gas has to be passed through the retort to effect a comparatively small amount of " work " in breaking down the gels of a torbanite. Furthermore, the gas has to enter the retort at a higher temperature than is required, since it cools quickly owing to its low specific heat. Inert gases also dilute the rich incondensable gases given off by the torbanite and render them less valuable.

Attempts to obtain a yield of ammonium sulphate from torbanites are not worth while : the quantity of ammonia yielded by a torbanite is at the best small, and the richer the torbanite the smaller the yield of ammonia in proportion to the oil.

Since the best results from a rich torbanite are only obtainable at the lowest possible temperature compatible with a reasonable rate of through-put and adequate extraction, the crushing of the raw material before retorting is advisable. The action of breaking down the gels to form oil is a surface one, and the greater the surface exposed the better. This indicates the advisability of horizontal or inclined retorts, in which the charge is constantly disturbed by stirrers or paddles or by rotation of the retort. With such processes, however, provision must be made for preventing dust from passing over to the condensers, a difficulty which has been experienced with several plants dealing with crushed material.

Digesters, if capable of operating at temperatures of 300° C. or slightly more, are eminently suitable for dealing with torbanite deposits, and may possibly prove to be even more efficient than true retorts. A wide field of research is opened up by the question of digester versus retort, but it is probably only with really rich material that the former will show the most decided advantages.

Speaking broadly, the solution of the difficulties besetting the extraction of oil from torbanites is to be found in the discovery or invention of a process which can be operated at quite a low temperature, which gives a high through-put for its size, and, most important of all, which is inexpensive to erect and to operate, and is as nearly automatic as possible. These may seem counsels of perfection, but they are founded upon many exhaustive practical tests with a variety of processes and materials ; so much of the preliminary experimental work has already been done, that a really efficient process may be said to be within sight.

## The Gaseous Products of Shale Retorting: Their Composition and Possible Utilization.

By Prof. Alfred W. Nash, M.Sc., F.C.S., M.I.Mech.E. (Member).

The process of retorting oil-shales and torbanites consists in subjecting these materials to the action of heat, whereby the complex kerogen molecules are broken down, probably in several stages, giving rise to oils, and also, in addition, to permanent gas. The gases produced by this thermal degradation contain oxides of carbon, hydrogen, saturated and unsaturated hydrocarbons, and hydrogen sulphide as well as ammonia. According to McKee and Manning, several stages can be distinguished in this process, as evinced by the type and quantity of gaseous products. These authors believe that the kerogen decomposes, on heating, into a bituminous substance insoluble in organic solvents, then into a soluble bitumen, which is further split up into hydrocarbons and permanent gases such as hydrogen and methane. Carbon dioxide is evolved in quantity in the early stages of the decomposition, probably in the reaction producing soluble bitumen from the kerogen, and also at a later stage due to the decomposition of inorganic carbonates. The reaction producing the intermediate bitumen is also attended by an evolution of sulphuretted hydrogen and ammonia. The production of hydrogen and unsaturated and saturated hydrocarbon gases occurs during the thermal decomposition of the intermediate bitumen, *i.e.*, during the cracking of the bitumen.

The gas evolution diminishes after the oil has been distilled off, but quantities of hydrogen, methane, and carbon monoxide (produced by the reaction $CO_2 + C \rightarrow 2CO$) continue to be evolved long afterwards.

In large scale practice, the composition and volume of gas produced by the decomposition of shale depend on a large number of factors, among which may be mentioned the following :—

(1) Character and richness of shale or torbanite.
(2) Type of retort and retorting conditions.
(3) Speed of retorting.
(4) Temperature attained by shale in retort.
(5) Use of steam or producer gas for internal heating.

Regardless of the exact mechanism of the conversion of kerogen into oil and gas, the process is fundamentally the decomposition or cracking of heavy and complex molecules to simpler ones. It is

possible to control this process in various ways so that, for example, only gaseous products are obtained; though it is doubtful whether oil can be produced without the formation of some gas as well.

Of the factors influencing the yield and composition of the gas, undoubtedly the most important are the retorting conditions and the maximum temperature of distillation. Thus, for example, if conditions in the retort are such that oil vapours come in contact with heated surfaces, extensive cracking of the oil may occur with consequent enrichment of the gas, both as regards quantity and calorific value, at the expense of the oil yield. The use of steam or producer gas for internal heating materially alters the type of gaseous products, the gases then being of much greater volume but of lower calorific value.

The effect of the temperature of retorting on the yield and composition of the gaseous products has been investigated by Kogerman on a laboratory scale using the Estonian shale, "Kukersite," and his results are given below. The duration of retorting was in each case two hours:—

| Temp. °C. | Yield of Gas cu.ft. per ton at 0° & 760 mm. | Percentage Composition of Gas. $H_2S$ | $CO_2$ | $C_nH_{2n}$ | CO | $C_nH_{2n+2}$ | $H_2$ | $N_2$ |
|---|---|---|---|---|---|---|---|---|
| 500 | 2250 | — | 22·5 | 28·2 | 9·3 | 34·0 | 4·2 | 1·8 |
| 600 | 3000 | 2·1 | 19·6 | 24·8 | 11·2 | 26·6 | 10·8 | 7·8 |
| 700 | 4500 | 2·2 | 15·6 | 22·0 | 12·5 | 19·6 | 22·9 | 5·2 |
| 900 | 7200 | — | 7·4 | 20·2 | 16·4 | 12·9 | 33·0 | 9·1 |

The decrease in the proportion of unsaturated and saturated hydrocarbons and the increase in the amounts of carbon monoxide and hydrogen with rising temperature of retorting, should be noted.

Very few figures are available as regards the yield of gas and oil produced in the retorting of South African shales in well-known types of retorts, but it may be safely assumed that the South African shales will compare very well both as regards volume and quality of gaseous products of retorting with the richer types of European shales.

Fleischmann has published some results obtained by the Jura-Olschiefer-Werke A.G. on the retorting of shale in the Thyssen retort. The yield of crude gas was about 1300 cu. ft. per ton of shale while the gas had the composition:—

$H_2S$ 4·8, $CO_2$ 10·6, $C_nH_{2n}$ 15·6, $O_2$ 0·4, $H_2$ 25·4, CO 3·2, $CH_4$ 22·8, $C_2H_6$ and homologues 13·3, and $N_2$ 3·9 per cent.

The high proportions of saturated and unsaturated hydrocarbons in the gas are noteworthy and are characteristic of externally-heated retorts without steaming.

Some large-scale tests, carried out in England, on the externally-heated "Fusion" retort, gave the following yields of gas and oil from various shales :—

| Shale. | Gallons of Oil per Wet Ton. | Cu. ft. of Gas per Wet Ton. |
|---|---|---|
| S. African Torbanite .. | 96 .. | 1770 |
| Estonian Shale .. .. | 65 .. | 1340 |
| Nova Scotia Shale .. | 28·2 .. | 1120 |

## Use of Steam.

The employment of steam in the retorting process, a practice which originated with the Scottish shale industry, was found to serve numerous purposes. In modern Scottish practice the shale is first retorted at a moderate temperature (900° F.) and then passes to a zone of higher temperature (maximum of 1800° F.), where steam enters the retort. Not only does this effect an economy in heat, since the steam is superheated by contact with the spent shale which it itself cooled, but also a more efficient distribution of heat is ensured. At the same time, at the temperature obtaining in the lower part of the retort, the steam reacts with the carbon in the spent shale according to the equations :—

$$C + H_2O = CO + H_2$$
$$C + 2H_2O = CO_2 + 2H_2$$

The gaseous products of retorting are thus diluted by the addition of large volumes of hydrogen and oxides of carbon, though the calorific value of the gas is at the same time reduced.

The steaming process was extremely valuable to the Scottish industry because the yield of ammonia was thereby vastly increased while the oil quality was improved, since cracking of the oil in the retort was reduced by the presence of steam.

The normal Scottish practice gives about 9800 cu. ft. of gas per ton of shale, a typical analysis being as follows :—

| | Per cent. |
|---|---|
| $H_2S$ .. .. .. .. .. | trace. |
| $CO_2$ .. .. .. .. .. | 20·0 |
| CO .. .. .. .. .. .. | 4·3 |
| $H_2$ .. .. .. .. .. .. | 34·2 |
| $C_nH_{2n}$ .. .. .. .. .. | 3·1 |
| $CH_4$ .. .. .. .. .. | 10·8 |
| $O_2$ .. .. .. .. .. | 5·1 |
| $N_2$ .. .. .. .. .. .. | 22·5 |

Calorific value 302·5 B.Th.U. per cu. ft. (gross) or 271·4 B.Th.U. per cu. ft. (net).

Retorts which are internally heated by hot flue gases or by producer gas, give rise to very large volumes of gas of low calorific value, from which the light liquid hydrocarbons, formed during the shale distillation, are difficult to separate. The Pintsch retort is

typical of the internally heated producer type of retort functioning as a retort and producer simultaneously. A battery of these retorts has been erected in Estonia for treating the native kukersite. About 21,000 cu. ft. of permanent gas per ton of shale are produced, having a heating value of about 90 B.Th.U. per cu. ft., and a composition varying between the limits :—

| | |
|---|---|
| $CO_2$ .. .. .. .. .. | 18·0 to 19·0 per cent. |
| CO .. .. .. .. .. .. | 2·0 „ 5·0 „ |
| $O_2$ .. .. .. .. .. .. | 0·2 „ 0·6 „ |
| $CH_4$ .. .. .. .. .. | 1·0 „ 2·0 „ |
| $C_2H_4$ .. .. .. .. .. | 0·3 „ 0·6 „ |
| $C_nH_{2n}$ .. .. .. .. .. | 0·5 „ 1·0 „ |
| $H_2$ .. .. .. .. .. .. | 0·0 „ 3·8 „ |
| $N_2$ .. .. .. .. .. .. | About 70 per cent. |

Finally, the high temperature retorting of shale has been carried out in Estonia and elsewhere for the manufacture of gas for lighting and power purposes. In the gas plants at Tartu and Tallinn (Estonia) the oil-shale is carbonised in horizontal retorts and the yield of gas is about 10,000 cu. ft. per ton. The temperature employed is about 900°—1000° C., while the resulting gas has the composition :—

| | |
|---|---|
| $CO_2$ .. .. .. .. | 13·3 per cent. |
| $C_nH_{2n}$ .. .. .. .. | 6·6 „ |
| $C_2H_4$ .. .. .. .. | 0·6 „ |
| CO .. .. .. .. .. | 19·3 „ |
| $H_2$ .. .. .. .. .. | 26·2 „ |
| $CH_4$ .. .. .. .. | 22·6 „ |
| $N_2$ .. .. .. .. .. | 11·4 „ |

Summing up, it may be said that dry distillation of shales and torbanites up to about 700° C. gives rise to moderate quantities of gas of a high calorific value and containing large amounts of gaseous hydrocarbons. The yield and quality of the gas is increased at the expense of the oil yield in cases where the oil vapours are cracked by coming in contact with hot surfaces, *i.e.*, in badly designed retorts. The use of steam increases the yield of gas, at the same time reducing its calorific value owing to dilution with hydrogen and oxides of carbon. The high temperature carbonisation process gives rise almost exclusively to gaseous products. In certain internally heated and producer type retorts, large quantities of low calorific value gas are obtained containing high proportions of nitrogen and oxides of carbon.

### Gas Yields from South African Shales.

The quantities of gas available in large-scale retorting of South African shales and torbanites have not been recorded systematically and more data are urgently required on this matter. However, figures are available regarding the laboratory retorting of many

South African shales and torbanites, carried out by Prof. Stanley, of the Witwatersrand University, who found that gas yields of 2000–6000 cu. ft. per ton were obtained, but the gas analyses have not been published.

Samples of the Ermelo torbanite examined by us in a small-scale laboratory retort which was heated up to about 700° C., gave about 2500 cu. ft. of gas per wet ton, the analysis of this gas being :—

| | |
|---|---|
| $CO_2+H_2S$ .. .. .. .. | 7·7 per cent. |
| Higher Olefines .. .. .. | 3·5 ,, |
| $C_2H_4$ .. .. .. .. | 6·8 ,, |
| CO .. .. .. .. .. | 7·0 ,, |
| $H_2$ .. .. .. .. .. | 27·3 ,, |
| $CH_4$ .. .. .. .. | 23·5 ,, |
| $C_2H_6$, etc. .. .. .. | 23·0 ,, |
| $N_2$ .. .. .. .. .. | 1·2 ,, |

Results of large-scale retorting of South African torbanite in the Fusion retort, mentioned previously, gave about 1770 cu. ft. of gas per ton of wet shale, the gas being probably very rich.

## The Utilization of Shale-Gas.

The main use of the gaseous products of shale retorting in Scotland, Estonia, France and other countries is as a fuel for heating retorts. In Scotland, where the shale finally attains a high temperature (up to 1800° F.), most of the gases are utilised in this way, but in Estonia only part of the permanent gases of distillation is used for heating the retorts. Moreover, where the plant is of the externally heated type, a very rich gas is obtained which might more profitably be used for other purposes. It is suggested that the utilisation of spent shale to yield producer gas or other low grade gases, suitable as fuel for plant requirements, might render possible the use of the richer permanent gases of shale distillation for other purposes. In this connection it is interesting to note that the Estonian Shale Oil Co. is manufacturing a producer gas from spent shale, or from spent shale mixed with raw shale, at Püssi, Estonia. This gas is said to possess a calorific value of 180 B.Th.U. per cu. ft., the yield being very variable, viz., from 900 to 4300 cu. ft. per ton.

The use of rich, hydrocarbon-containing gases for enriching ordinary coal gas or blue water gas (or even of lower grade gaseous fuels) has received much attention recently, especially in U.S.A., where propane and butanes, extracted from natural gas, are being utilised in this way. Moreover, in Germany coke-oven gas is being resolved into its constituents by a process of low temperature fractionation, and compressed hydrocarbon gases are being offered

for various industrial purposes. In particular the production of methane from coke-oven gas on a large scale by the Concordia Bergbau A.-G. may be mentioned.

The gases from shale distillation contain appreciable quantities of hydrogen, the amount of which is considerably increased by steaming at high temperatures. It has been proposed by Matignon to utilise this hydrogen for the synthesis of ammonia. For instance, the distillation of Autun (France) shales by the Société Lyonnaise des Schistes Bitumineux, yields 2200 cu. ft. per ton of a gas consisting of $CO_2$ 22, CO 5, hydrocarbons 40 and $H_2$ 33 per cent. When distilled in accordance with Scottish practice (with steaming) the yield of gas is greatly increased—namely, to about 24,000 cu. ft. per ton, the gas now possessing the composition as follows:—

| | | |
|---|---|---|
| $CO_2$ | 20·8 | per cent. |
| $C_nH_{2n}$ | 0·8 | ,, |
| $O_2$ | 3·6 | ,, |
| CO | 4·4 | ,, |
| $CH_4$ | 6·6 | ,, |
| $H_2$ | 25·6 | ,, |
| $N_2$ | 38·2 | ,, |

Matignon calculates that, if this hydrogen were separated by the Claude process (low temperature fractionation), the distillation of 100,000 tons of shale would yield sufficient hydrogen for the production of 8500 tons of ammonia or of 35,000 tons of sulphate of ammonia. The utilisation of the hydrogen of coke-oven gas as a raw material for the synthesis of ammonia has been completely worked out in Europe, where it is regarded as the cheapest source of hydrogen. For example, the synthetic ammonia plant of the Union Chimique Belge obtains its hydrogen from coke-oven gas by the low temperature fractionation process of Linde-Bronn, while the same process is used by the Gasverarbeitungs-Gesellschaft in Westphalia for their Mont-Cenis works. Thus it would appear practicable to utilise the permanent gases of shale distillation as a source of hydrogen, especially if the steam-carbon reaction of Scottish practice were incorporated in the retorting process.

The olefine hydrocarbons present in the shale-distillation gases (ethylene, propylene, butylenes and a little butadiene) might readily be used for purposes other than as fuel, without appreciable diminution of the calorific value of the gas. The olefine content of shale gases may be as high as 20 per cent., especially in gases from externally heated retorts, but is usually less than this. Since, however, it has been seriously proposed to utilise the olefines, particularly ethylene, in coke-oven gas containing usually not more than 3 per cent. of olefines for the production of alcohol, it would appear entirely feasible to use the richer shale gases for this purpose. Owing to their great chemical reactivity and uusualn

power of condensation, olefine gases are readily converted into higher hydrocarbons (some of which have been proposed as lubricants), alcohols and glycols which are useful as solvents and raw materials for chemical manufacture. Samples of gases obtained by the laboratory retorting of various shales examined in our laboratories were found to contain ethylene, propylene and the butylenes, as well as smaller amounts of butadiene, though ethylene was usually the preponderating constituent. It is suggested that, before burning shale gas under retorts, the olefine gases should first be removed, at least in part, and converted into alcohols and other products.

In U.S.A. the olefine gases present in "cracking" gas are being utilised for the preparation of isopropyl, and other alcohols, while ethylene and propylene glycols and their derivatives are being manufactured in large quantities from the same source. It is of interest to note that recent patents indicate that ethylene may be converted directly into alcohol, without the intervention of sulphuric acid, by direct interaction with steam at high temperatures and pressures, a process of profound importance to producers of large quantities of gaseous olefines.

Recent research work has indicated that the gaseous paraffin hydrocarbons, such as methane and ethane, may be utilised for the production of a variety of valuable materials. For instance, both methane and ethane can be converted, by thermal treatment, into benzene and other aromatic hydrocarbons, while ethane can be readily dehydrogenated to give good yields of ethylene. From the point of view of the Union, research prosecuted in another direction is of perhaps greater importance—namely, that in which hydrocarbons such as methane, ethane and ethylene are converted into hydrocyanic acid by interaction with nitrogen compounds such as ammonia or oxides of nitrogen. The production of cyanides from methane by interaction with ammonia at high temperatures is a process which is being tested on a commercial scale and bids fair to absorb very large quantities of that gas.

The trend of modern research in the utilisation of the olefines present in "cracking" gas, etc., in the U.S.A., is in the direction of the controlled polymerisation of these olefines to give motor fuels of high anti-knock value, and also of lubricating oils. This polymerisation may be conveniently effected by heating under pressure with or without catalysts as well as by the silent electric discharge and other forms of energy. The Allenet process for the manufacture of lubricating oils involves the polymerisation of gaseous olefines in the presence of anhydrous aluminium chloride suspended in a middle oil, the products being said to be good lubricants, comparable with the best American products.

## Gases from the Cracking of Shale-Oil.

A shale-oil industry can only be rendered profitable when its products can be produced at a cost and of a quality comparable with those of the petroleum industry. This fact renders it very necessary that all the possible by-products of shale retorting shall, as far as possible, be carefully utilised and converted into sources of revenue.

One of the most important processes in this connection is the cracking of certain of the higher fractions of shale-oil so as to produce motor spirit. Egloff has published some figures on the liquid phase cracking of various shale-oil distillates obtained from American, Scottish, Australian, French and Estonian shales, and reports very favourably on the yield and quality of the spirit produced. The permanent gas obtained was very rich, having a calorific value of about 1300 B.Th.U. per cu. ft., and would, no doubt, be similar in composition to a normal liquid phase cracking gas containing 10 to 20 per cent. of olefines and 80 per cent. of gaseous paraffin hydrocarbons. The yield of gas varied from 970 to 600 cu. ft. per bbl. of oil on a non-residual basis and from 596 to 168 cu. ft. on a residual oil basis. With an increase in the amount of cracking of shale-oil, enormous quantities of rich cracking gas will be produced.

It is probable that better results will be obtained by cracking the higher fractions of shale-oil by means of a vapour phase process which normally employs temperatures of 600° C. and over, compared with 450° C. for liquid phase cracking. Such a vapour phase process—namely, the Gyro,—is apparently being used for much lower grade hydrocarbon material. The point of interest is that much more gas is produced in vapour phase cracking (1000 to 1500 cu. ft. per bbl.), containing very high percentages of olefine hydrocarbons, and, at the same time, a highly anti-knock gasoline is obtained. The average composition of a gas produced by the vapour phase cracking of petroleum fractions is as follows :—

| | |
|---|---|
| $H_2$ .. .. .. .. .. | 7·0 per cent. |
| $C_2H_4$ .. .. .. .. | 27·0 „ |
| $C_3H_6$ .. .. .. .. | 16·0 „ |
| $C_4H_8$ .. .. .. .. | 9·0 „ |
| Butadiene .. .. .. | 1·0 „ |
| $C_nH_{2n+2}$ .. .. .. | 39·6 „ |

Thus the vapour phase cracking of shale-oils may be expected to give rise to large quantities of olefine gases which may be used as sources of alcohols and other substances.

In this connection the vapour phase cracking of Estonian shale-oil distillates at a rather high temperature (750° C.) in a tinned iron tube has been investigated by Weiderpass. The light fraction obtained, of boiling point up to 170° C., was 30 per cent. of the

original shale-oil or 39 per cent. of the distillate, and consisted largely of aromatic hydrocarbons. The gas obtained during this cracking process, probably in considerable quantity, since the temperature was abnormally high, had a calorific value of 1200 B.Th.U. per cu. ft., and the following percentage composition :—

| | |
|---|---|
| $CO_2$ .. .. .. .. | 2·3 per cent. |
| $C_nH_{2n}$ .. .. .. .. | 18·7 ,, |
| CO .. .. .. .. .. | 15·3 ,, |
| $H_2$ .. .. .. .. .. | 17·5 ,, |
| $C_nH_{2n+2}$ .. .. .. | 39·2 ,, |
| $N_2$ .. .. .. .. .. | 7·0 ,, |

Weiderpass considers that cracking in this way would be economic if the yield of light oil amounted to 30 per cent. of the oil charged.

## Summary.

It has been pointed out that the permanent gases of shale distillation contain valuable gaseous materials which could undoubtedly be utilised in various ways other than for heating the retorts.

In particular, the olefine content of the gas, which may be as high as 20 per cent., is important, and it is considered both uneconomical and scientifically undesirable to use such valuable chemical raw materials as fuel for retorts when lower-grade gaseous fuels, such as producer gas, can be conveniently used instead.

The increasing scientific and technical interest in the utilisation of the lower gaseous paraffin hydrocarbons, such as methane and ethane, has been noted. In particular the process of preparing cyanides by the interaction of ammonia, or other nitrogen compounds, with these paraffin gases at high temperatures, now being investigated in Europe, would seem to possess considerable possibility of commercial success in the Union of South Africa.

Department of Oil Engineering and Refining,

University of Birmingham.

# THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

## PERSIAN BRANCH.

## THIRD ANNUAL GENERAL MEETING.

THE THIRD ANNUAL GENERAL MEETING of the Persian Branch of the Institution of Petroleum Technologists was held at the Abadan Gymkhana Club, Abadan, on Wednesday, April 30th, 1930, the Chair being taken by Mr. E. C. Brewster.

The Minutes of the last Annual General Meeting were read and adopted on the proposal of Mr. C. S. CLEVERLY, seconded by Mr. G. STEVENSON.

The Annual Report and Balance Sheet for the year 1929 were then read.

The CHAIRMAN, in commenting on the Annual Report and Balance Sheet, said that the credit balance of £84 might be considered satisfactory. He hoped that members would make full use of the funds available, and that a satisfactory number of papers would be presented at meetings. To cover such local expenses the Parent Institution had given approval to a local subscription of ten shillings. The response had been very gratifying, all members with the exception of one having subscribed. The Balance Sheet showed subscriptions received up to the end of 1929. Subscriptions for 1930 would of course rank for the current year. In connection with an Epidiascope, which it was agreed would be very useful in illustrating the papers submitted, funds might now be considered available and Mr. C. J. Wright had promised to look into the matter while home in England. In connection with the 1929 Annual Dinner, the social success of the function more than justified the small debit incurred.

On the motion of Mr. R. G. BROWN, seconded by Mr. C. S. CLEVERLY, the Annual Report was adopted.

The Balance Sheet was adopted on the proposal of Mr. R. G. BROWN, seconded by Mr. W. HAWKINS.

The Ballot Papers for the election of two new members to the Committee were scrutinised, and Messrs. A. N. Baylis and C. J. Wright declared elected. The Committee for the current year is therefore as follows :—

Mr. S. W. Adey. Mr. W. E. Aylwin. Mr. A. N. Baylis.
Mr. E. C. Brewster. Mr. C. S. Cleverly. Mr. D. G. Smith.
Mr. C. J. Wright.

It was unanimously agreed that an attendance at an Annual General Meeting of 20 per cent. of the members resident in Abadan at the time should constitute a quorum.

This concluded the business of the meeting.

## THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

### PERSIAN BRANCH.

### ANNUAL REPORT, 1929.

During the past year, the third since the formation of the Branch, the number of papers read has been somewhat below average. The interest, however, has increased as shown by the number of members and visitors who attended.

*Meetings.*—Mr. S. W. Adey read a paper on "Fostering a New Spirit."

During the present year Mr. G. L. Kennaby read a paper on "Liquefied Gas," which has gone home for publication in the Institution's Journal.

A paper has been received from Mr. P. Meyer entitled "The Vapour Pressure Curves of Motor Spirits," and will be read shortly.

A further paper is in course of preparation by Mr. W. J. Galloway.

*Membership.*—The membership has shown a net increase of 12 over the figures at the end of last year, the comparative figures being :—

| | 1928 | 1929 |
|---|---|---|
| Members .. .. .. | 12 | 18 |
| Associate Members .. | 45 | 47 |
| Students .. .. .. | 3 | 4 |
| Associates .. .. .. | 5 | 8 |
| | 65 | 77 |

*Social.*—A successful dinner was held on Friday, November 22nd, 1929, and attended by 72 people, including members and guests. Mr. W. E. Aylwin was in the Chair. Toasts were arranged as follows :—

| | |
|---|---|
| "The Petroleum Industry" .. | Mr. E. C. Brewster. |
| Reply .. .. .. .. | Mr. T. L. Jacks. |
| "Our Guests" .. .. .. | Mr. C. C. Mylles. |
| Reply .. .. .. .. | Mr. H. F. Bishop. |
| "The Persian Branch" .. .. | Mr. E. H. O. Elkington. |
| Reply .. .. .. .. | Mr. W. E. Aylwin. |

It was regretted that Mr. E. C. Brewster was unable to attend the dinner on account of indisposition. Under these circumstances, the Honorary Secretary read the toast proposed to "The Petroleum Industry."

*General.*—During the course of the year the question of a levy to local members to cover the cost of printing papers, etc., read before

the local Institution was referred to the Parent Institution, who stated that such a subscription was customary among local branches and had their full support.

The question of extending the powers of members domiciled abroad to include voting powers for the election of Council nominees of the Parent Institution, was referred to London and has been put before the Council. We now await their decision.

The question of the poor nature of the wrappers which are used to enclose the Institution's Journals has been taken up with the publishers, who have promised to improve the present quality of the wrapper.

*Committee.*—The following members have served on the Committee during the past year :—

Mr. W. E. Aylwin (*Chairman*).
Mr. S. W. Adey.
Mr. E. C. Brewster.
Mr. C. S. Cleverly.
Mr. H. W. Rigden.
Mr. D. G. Smith.
Mr. C. J. Wright (*Hon. Secretary*).

According to the Constitution, two members have to retire each year and can offer themselves for re-election. Mr. H. W. Rigden and Mr. C. J. Wright retired. The following members were nominated for election to the two vacancies so made :—

Mr. A. N. Baylis.
Mr. W. J. Galloway.
Mr. P. Meyer.
Mr. H. W. Rigden.
Mr. C. J. Wright.

Ballot papers were circulated to Abadan members. After scrutinising the ballot papers, in order to elect the two new members, it remains for the Committee to elect, at a Committee Meeting, a Chairman and an Honorary Secretary for the current year.

*Balance Sheet.*—The Balance Sheet shows a favourable balance of approximately £84.

*Papers Submitted.*—During the past year the Committee has been active in reminding members of the breadth and scope of our industry, and in inviting them to submit papers. We hope that a hearty response will be forthcoming.

(Signed) PERCY MEYER,
Acting Hon. Secretary.

## THE INSTITUTION OF PETROLEUM

### REVENUE ACCOUNT FOR THE

#### EXPENDITURE.

| | £ | s. | d. |
|---|---|---|---|
| To Sundry Expenses .. .. .. .. .. .. .. | 3 | 15 | 0 |
| „ Annual Dinner .. .. .. .. .. .. .. | 7 | 15 | 11 |
| „ Depreciation on Furniture .. .. .. .. .. | 1 | 5 | 7 |
| „ Cost of Books, Literature and Printing .. .. .. | 6 | 0 | 9 |
| „ Balance .. .. .. .. .. .. .. .. | 84 | 7 | 0 |
| | £103 | 4 | 3 |

### BALANCE SHEET AS AT

#### LIABILITIES.

| | £ | s. | d. |
|---|---|---|---|
| Balance from Revenue Account .. .. .. .. .. | 84 | 7 | 0 |
| | £84 | 7 | 0 |

Abadan,
April 15th, 1930.

## TECHNOLOGISTS (PERSIAN BRANCH).

YEAR ENDED DECEMBER 31st, 1929.

### INCOME.

| | £ | s. | d. |
|---|---|---|---|
| By Balance at January 1st, 1929 .. .. .. .. .. | 55 | 4 | 3 |
| „ Subscriptions (Local) .. .. .. .. .. .. | 12 | 0 | 0 |
| „ London Contributions .. .. .. .. .. .. | 36 | 0 | 0 |
| | £103 | 4 | 3 |

MARCH 31st, 1930.

### ASSETS.

| | | | | £ | s. | d. |
|---|---|---|---|---|---|---|
| Cash with A.P.O.C. .. .. .. .. .. .. .. | | | | 75 | 17 | 2 |
| Provisions Returned to Stores (credited in January, 1930) .. | | | | 4 | 12 | 10 |
| Furniture and Fittings .. .. .. .. | £5 | 2 | 7 | | | |
| Less 20 per cent. Depreciation on original value .. .. .. .. .. .. | 1 | 5 | 7 | 3 | 17 | 0 |
| | | | | £84 | 7 | 0 |

Signed: P. MEYER, for C. J. WRIGHT,
*Hon. Treasurer.*

ROBERT CLIBB, *Hon. Auditor.*

## THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

### TRINIDAD BRANCH.

A MEETING of the Trinidad Branch of the Institution of Petroleum Technologists was held at the Apex Club, Fyzabad, on Wednesday, February 26, 1930, when the Chair was taken by Mr. A. Frank Dabell.

### Gas Conservation and Pressure Control.

By G. H. SCOTT, B.Sc. (Associate Member).

The author discussed the necessity of Gas Conservation in the economic recovery of oil, the relationship of correct well spacing and the necessity to reduce friction in the designing of flow strings and surface connections.

He then dealt at length with the methods of effecting back pressure control on naturally flowing wells, a précis of which follows.

In naturally flowing wells control can best be assured by one or a combination of the following methods : variation in depth of tubing, variation in size of tubing, or the use of chokes or beans.

Tubing depth must be considered in conjunction with the pressure conditions of the well. If a high-pressure well is tubed low, the accumulated gas pressure outside the tubing may depress the fluid level so that the gas will blow through. In such cases it may be necessary to bleed off some of the gas, a practice to be condemned. The better method is to raise the tubing and thus ensure an increase of back pressure on the sand.

Each well requires its own special treatment and tubing depths must be determined by trial and error, careful records being kept. On principle a low depth is to be recommended and in same cases maximum efficiency is obtained by progressive lowering of the tubing to gradually reduce back pressure.

The main reason for lowering tubing is to decrease the fluid head, which causes increased velocity and consequent increased frictional head. In high-pressure wells the advantages of increased velocity, with a decrease in gas slippage, may be offset by increased friction head. Thus tubing may decrease initial flows but gas-oil ratios will be lower.

Probably the best means of applying pressure control is by varying the size of tubing. The fluid in the tubing is an oil-gas mixture, and above the critical velocity turbulent flow occurs, with a tendency for the gas to flow faster than the oil until only gas will travel. This condition can be overcome by raising the tubing, by choking at the

well head, or by increasing tubing size, to decrease the velocity to below the critical limit. Research shows that the maximum quantity of gas that can be passed through tubing is as follows :—

| Tubing. | | Maximum Flow of Gas. |
|---|---|---|
| Diameter. | Weight lbs./ft. | M. cu. ft./day. |
| 2 in. .. | 4.6 .. | 330 |
| 2½ in. .. | 6.4 .. | 564 |
| 3 in. .. | 8.5 .. | 992 |
| 4 in. .. | 12.6 .. | 2040 |

The tubing lowered should be of a size to ensure a velocity near to the critical velocity to ensure a larger flowing life. The correct size of tubing is of importance to allow low setting to obtain maximum benefits.

A rough idea as to whether the tubing is correct can be obtained by varying the choke; if too small there will be only slight reactions to bean changes, and if too large the effect on gas production will be greater than on oil yield. If correct the percentage decreases in gas and oil will be roughly equal.

Choke sizes should be given in terms of the cross-sectional area and bean changes should not be too drastic or erratic. A change of 1/32 in. per day is suggested as a maximum and time should be allowed between changes to ensure that the well has settled down to the new conditions.

An initial decline in gas-oil ratio after a choke change is not proof that the change has been beneficial. The trend of gas-oil ratios, before and after the change, must be known to draw trustworthy deductions.

The size of choke giving optimum value only applies to the existing pressure conditions, and as pressure declines choke readjustments become necessary. The installation of orifice meters at all flowing wells would ensure any increase in gas-oil ratio being noted at once.

It is often stated that, when a well ceases to flow and a pump is applied, gas is a nuisance. In a pumping well gas is present both in the free and in the occluded state, the ratio being largely dependent on the pump submergence below operating fluid level. As oil passes the standing valve into the barrel, the pressure decrease will liberate gas. This gas will not be forced past the travelling valve but will be merely expanded and contracted by the motion of the plunger, so that there will be no suction effect tending to raise the standing valve. It may be taken that the filling of the barrel is due to fluid head above the standing valve and, as this head is a function of the

potential pressure, gas conservation is still necessary to ensure maximum extraction.

In pumping wells pressure control can best be obtained by correct submergence of the working barrel and size and speed of pump. Once correct submergence is obtained a constant pumping level should be maintained by withdrawing the fluid at the same rate as it flows into the well. Intermittent pumping is not to be recommended.

Open casing heads, with waste of natural gas energy, should only be allowed when absolutely necessary. If a well fails to pump with a closed casing head, the maintenance of a small back pressure by means of beans might allow of economic pumping and would certainly aid gas conservation.

In conclusion stress is laid on the importance of conserving gas energy, and pressure control should be extended to cover the whole producing life of the well. A flowing well is mechanically inefficient, and increase of efficiency would lead to increase of potential extraction. Production from a reservoir must be governed by the basic laws of fluid flow, of which a production engineer should have a general knowledge. To recommend the shutting down of highly inefficient wells is only analogous to a merchant closing an unprofitable branch and thus increasing gross profits.

In the discussion the following took part:—Mr. W. J. C. Cooke, Mr. E. G. Rooks, Mr. L. A. Bushe, Lt.-Col. H. C. B. Hickling, Mr. J. S. Parker, Mr. Richards, Mr. R. N. Kirby, Mr. W. Tomalin and Mr. A. Frank Dabell.

# Notes on the Viscosity-Temperature Relations of Lubricating Oils.*

By W. L. Baillie, F.I.C.

## 1. Eckart's Logarithmic Relation.

Of the various empirical formulas which have been proposed from time to time to express the relation between the viscosity and temperature of lubricating oils, probably the most practical is that due to Eckart (Day, Handbook of the Petroleum Industry, Vol. 1, p. 390). There appears, however, to be a certain division of opinion as to whether the absolute viscosity or the kinematic viscosity should be employed in formulation, so that both the following equations are in current use :—

$$\log A = m \log \theta + K \ldots \ldots (1)$$

$$\log V = n \log \theta + c \ldots \ldots (2)$$

In these equations A denotes the absolute viscosity (poises) of the oil, $\theta$ is the temperatures (° F.), V is the kinematic viscosity and m, K, n, and c, are constants characteristic of the oil. The second of these equations has been found satisfactory as an interpolation formula in a considerable number of cases, but it was considered desirable that the relative merits of the two equations should be investigated.

For this purpose certain results recorded by Archbutt & Deeley (Lubrication and Lubricants, 5th Edn., pp. 230-233) appeared suitable. Particulars of the oils concerned are shown in the following tables:

Table I.

| Ref. No. (*a*) | Description of Oil. | Approximate Efflux Time (secs.) for 50 c.c. of oil at 150° F. (*b*) (Redwood Viscometer). |
|---|---|---|
| 1 | American Spindle, 0·885 .. .. .. | 45 |
| 2 | American Spindle, 860/870 .. .. .. | 52 |
| 3 | Light Machinery, Russian .. .. .. | 56 |
| 4 | Light Machinery .. .. .. .. | 62 |
| 5 | Solar Red, Engine .. .. .. .. | 74 |
| 6 | Bayonne, Engine .. .. .. .. | 84 |
| 7 | Queen's Red, Engine .. .. .. .. | 93 |
| 8 | Medium Machinery, Russian .. .. | 93 |
| 9 | Medium Dark, Engine .. .. .. | 101 |
| 10 | Filtered Cylinder, Valvoline .. .. .. | 273 |
| 11 | Cylinder, A .. .. .. .. .. | 372 |

(*a*) Employed in the succeeding tables.

(*b*) Calculated ; vide Note 4.

* Paper received March 20th, 1930.

TABLE II.

| Ref. No. | Absolute Viscosity (poises) at (a) 60° F. | 100° F. | 150° F. | 212° F. | Kinematic Viscosity at (b) 60° F. | 100° F. | 150° F. | 212° F. |
|---|---|---|---|---|---|---|---|---|
| 1 | 0·453 | 0·162 | 0·066 | 0·033 | 0·512 | 0·186 | 0·078 | 0·040 |
| 2 | 0·727 | 0·236 | 0·086 | 0·039 | 0·838 | 0·277 | 0·103 | 0·048 |
| 3 | 1·156 | 0·307 | 0·099 | 0·043 | 1·288 | 0·347 | 0·114 | 0·051 |
| 4 | 1·138 | 0·342 | 0·115 | 0·049 | 1·263 | 0·386 | 0·132 | 0·058 |
| 5 | 1·915 | 0·496 | 0·150 | 0·058 | 2·090 | 0·550 | 0·170 | 0·067 |
| 6 | 2·172 | 0·572 | 0·173 | 0·063 | 2·383 | 0·638 | 0·197 | 0·073 |
| 7 | 2·995 | 0·711 | 0·196 | 0·070 | 3·282 | 0·791 | 0·223 | 0·081 |
| 8 | 3·592 | 0·762 | 0·196 | 0·066 | 3·949 | 0·851 | 0·223 | 0·077 |
| 9 | 3·046 | 0·705 | 0·210 | 0·076 | 3·446 | 0·811 | 0·247 | 0·092 |
| 10 | — | 2·406 | 0·605 | 0·187 | — | 2·747 | 0·705 | 0·223 |
| 11 | — | 4·224 | 0·833 | 0·240 | — | 4·775 | 0·961 | 0·284 |

(a) from Archbutt and Deeley, loc. cit.

(b) Calculated from absolute viscosities and densities (not reproduced); kinematic viscosity = absolute viscosity ÷ density.

A convenient method of assessing the relative merits of the equations under consideration depends upon the fact that, if the experimental data (in this case the logarithms of the temperatures and the absolute or kinematic viscosities) are linearly related, the slope of the line representing them will be sensibly constant. The equations each contain two constants so that a value for the slope may be calculated from two results alone. Thus, by taking all the results for each oil in pairs, six values for m and n may be calculated where viscosities have been determined at four temperatures and three values where results are available at three temperatures. The percentage mean deviation from the mean is a useful criterion of the degree of constancy attained. The results of these calculations are summarized below.

TABLE III.

| Ref. No. | Absolute Viscosities. Mean Value of m. | Mean deviation from mean. Numerical. | % | Kinematic Viscosities. Mean Value of n | Mean deviation from mean. Numerical. | % |
|---|---|---|---|---|---|---|
| 1 | —2·088 | 0·057 | 2·73 | —2·035 | 0·058 | 2·85 |
| 2 | —2·337 | 0·071 | 3·04 | —2·284 | 0·069 | 3·02 |
| 3 | —2·617 | 0·079 | 3·02 | —2·567 | 0·084 | 3·27 |
| 4 | —2·515 | 0·082 | 3·26 | —2·464 | 0·079 | 3·21 |
| 5 | —2·791 | 0·075 | 2·69 | —2·741 | 0·071 | 2·59 |
| 6 | —2·830 | 0·105 | 3·71 | —2·781 | 0·093 | 3·34 |
| 7 | —3·001 | 0·087 | 2·90 | —2·951 | 0·084 | 2·85 |
| 8 | —3·188 | 0·077 | 2·42 | —3·138 | 0·073 | 2·33 |
| 9 | —2·933 | 0·030 | 1·02 | —2·880 | 0·025 | 0·87 |
| 10 | —3·400 | 0·004 | 0·12 | —3·340 | 0·012 | 0·36 |
| 11 | —3·806 | 0·139 | 3·65 | —3·743 | 0·148 | 3·95 |

The numerical values of the mean deviations average 0·073 and 0·072 for the absolute and kinematic viscosity data respectively and the percentage deviations average 2·60 per cent. in both cases. It would therefore appear that equations (1) and (2) express the

results equally well. For practical reasons, however, the second method of formulation is perhaps to be preferred.

Since viscosities diminish with rise in temperature, m and n are naturally negative in sign. It will be observed that, in general, m and n are numerically greatest for the most viscous oils, *i.e.*, by this method of representation the straight lines representing the most viscous oils have the greatest slopes. These slopes are, of course, distinct from the "slopes," usually so-called, of the usual Redwood-seconds-temperature curves but, as is shown in a later Note, an approximate relation may be established between them.

From the kinematic viscosities shown in table 2 and the mean value of n in table 3, the following values of the second constant, c, of equation (2) have been calculated:

TABLE IV.

| Ref. No. | Value of c. | Mean Deviation from mean Numerical. | % |
|---|---|---|---|
| 1 | 3·3297 | 0·0071 | 0·21 |
| 2 | 3·9927 | 0·0092 | 0·23 |
| 3 | 4·6605 | 0·0160 | 0·34 |
| 4 | 4·4938 | 0·0106 | 0·24 |
| 5 | 5·2037 | 0·0096 | 0·18 |
| 6 | 5·3403 | 0·0135 | 0·25 |
| 7 | 5·7772 | 0·0116 | 0·20 |
| 8 | 6·1865 | 0·0098 | 0·16 |
| 9 | 5·6622 | 0·0034 | 0·06 |
| 10 | 7·1180 | 0·0012 | 0·02 |
| 11 | 8·1537 | 0·0156 | 0·19 |

It will be noted that this constant resembles the preceding in being numerically greatest for the most viscous types of oil but, unlike n, c is always positive. The mean deviations average 0·0098, *i.e.*, 0·19 per cent.

The mean values of n and c found above have been employed to calculate the kinematic viscosities of the oils concerned at the temperatures stated in table 2 and the results are summarized below.

TABLE V.

| Ref. No. | 60° F. Calc. | 60° F. Error % (a) | 100° F. Calc. | 100° F. Error % | 150° F. Calc. | 150° F. Error % | 212° F. Calc. | 212° F. Error % |
|---|---|---|---|---|---|---|---|---|
| 1 | 0·514 | —0·39 | 0·182 | +2·20 | 0·080 | —2·50 | 0·039 | +2·56 |
| 2 | 0·854 | —1·87 | 0·266 | +4·14 | 0·105 | —1·90 | 0·048 | Nil |
| 3 | 1·248 | +3·21 | 0·336 | +3·27 | 0·119 | —4·20 | 0·049 | +4·08 |
| 4 | 1·295 | —2·47 | 0·368 | +4·89 | 0·135 | —2·22 | 0·058 | Nil |
| 5 | 2·137 | —2·20 | 0·527 | +4·36 | 0·173 | —1·73 | 0·067 | Nil |
| 6 | 2·496 | —4·53 | 0·603 | +5·80 | 0·195 | +1·03 | 0·075 | —2·67 |
| 7 | 3·388 | —3·13 | 0·750 | +5·47 | 0·227 | —1·76 | 0·082 | —1·22 |
| 8 | 4·044 | —2·35 | 0·814 | +4·55 | 0·228 | —2·19 | 0·077 | Nil |
| 9 | 3·477 | —0·90 | 0·798 | +1·63 | 0·248 | —0·40 | 0·092 | Nil |
| 10 | — | — | 2·742 | +0·18 | 0·707 | —0·28 | 0·223 | Nil |
| 11 | — | — | 4·526 | +5·50 | 1·014 | —5·23 | 0·278 | +2·16 |

(*a*) observed—calculated, as percentage of observed kinematic viscosity.

The maximum mean deviation is 5·80 per cent., and the average is 2·36 per cent. These figures are in some measure a criterion of the applicability of equation (2) as an interpolation formula.

It may be pointed out that the relation now under consideration is really a particular case of a general empirical equation due to Slotte, in which kinematic viscosity is used in lieu of absolute viscosity, as originally proposed. With this alteration the relation may be formulated

$$V = \frac{b}{(t + a)^\rho} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3),$$

in which V denotes the kinematic viscosity, t is the temperature (°C.), and the remaining symbols denote constants characteristic of the material. It should be noted that the exponent, $\rho$, in this equation is a positive quantity.

If now, $\theta$ °F. be the temperature on the Fahrenheit scale corresponding to t °C, we have

$$t = \frac{5}{9}(\theta - 32) \text{ and so}$$

$$t + a = \frac{5}{9}(\theta - 32) + a = \frac{5}{9}\left(\theta - 32 + \frac{9a}{5}\right)$$

whence

$$\frac{b}{(t + a)^\rho} = \frac{b}{(5/9)^\rho\ (\theta - 32 + 9a/5)^\rho} = \frac{h}{(\theta - 32 + 9a/5)^\rho} \quad \ldots\ldots (4)$$

in which $h = \dfrac{b}{(5/9)^\rho}$, a new constant.

Substituting in equation (3) from (4) we have

$$\log V = -\rho \log (\theta - 32 + 9a/5) + \log h \ldots\ldots\ldots\ldots (5)$$

If, now, $9a/5 = 32$, this reduces to

$$\log V = -\rho \log \theta + r \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

in which $r = \log h$ (a constant).

This is identical in form with equation (2) above. Eckart's logarithmic relation is thus a special case of Slotte's general relation, in which temperatures are expressed in the Fahrenheit scale and Slotte's constant a in the denominator takes the value 160/9 for all lubricating oils. It will be clear from Table V. that this is correct to within a close degree of approximation.

In an empirical expression it is unwise to assume that the constants used will admit of any real physical interpretation, but it may perhaps be pointed out that the constant c in equation (2) denotes the logarithm of the viscosity of the material at 1° F. Some parallelism might be expected between the values of this

constant and the cold tests of particular oils, and indications of this have in fact been obtained in certain cases.

It has already been suggested that equation (2) should be useful for interpolation, and in this connection it may be pointed out that the following form is convenient:—

$$\log\left(\frac{V_1}{V_2}\right) = \rho \log\left(\frac{\theta_1}{\theta_2}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

in which $V_1$ and $V_2$ denote viscosities (kinematic or absolute, as may be convenient) at temperatures $\theta_1$ and $\theta_2$° F. respectively, and $\rho$ denotes m or n, depending upon the basis of calculation adopted. The derivation of equation (7) will be obvious.

## Summary and Conclusions.

1. Eckart's logarithmic relation holds equally well for absolute and kinematic viscosities.

2. It gives results agreeing with experiment to within about ± 2·5 per cent.

3. It is applicable to a wide range of lubricants, from spindle oils to cylinder oils.

4. This relation is essentially a special case of a general relation due to Slotte.

5. A modified formula, suitable for interpolation, is noted.

## II. An Approximate Equation for Redwood-Seconds-Temperature-Curves.

It has been shown by Higgins (N.P.L. Collected Researches, Vol. XI., pp. 1—16) that the time of efflux of an oil from a short-tube viscometer is related to its kinematic viscosity by an equation of the type

$$V = AT - B/T \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

in which V denotes the kinematic viscosity, T the efflux time, in seconds, for standard volume of oil, and A and B are constants characteristic of the particular instrument used. It is also known (*cf.* Note I) that

$$\log V = n \log \theta + c \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

in which V denotes the kinematic viscosity, as before, $\theta$ is the temperature (° F.) and n and c are constants characteristic of each oil. This equation may obviously be transformed to read

$$V = w\,\theta^n \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

in which $\log w = c$.

Eliminating V between equations (1) and (3) we have

$$AT - B/T = w\,\theta^n \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

This equation involves as variables only the efflux time, T, and the temperature, $\theta$, and so represents the familiar "viscosity-temperature" curves of lubricating oils. It will be observed that by substitution of the appropriate values for the instrumental constants (A and B) this equation should be applicable to all short-tube viscometers used commercially. In the case of the Redwood instrument the values found by Higgins (*loc. cit.*) are

$$A = 0{\cdot}0026$$
$$B = 1{\cdot}715.$$

Equation (4) may, of course, be simplified by dividing throughout by one of the constants A, B or w, but the form given is general and is quite convenient in practice.

The validity of equation (4) has been tested by applying it to certain oils for which Redwood efflux times had been determined at a number of temperatures between 70° and 210° F. These determinations were made some years ago, and the numbers of the viscometers used cannot now be ascertained. As it was impossible to decide upon the individual instrumental constants in each case the values found by Higgins have been employed. It is believed that this has not introduced any substantial inaccuracy. The experimental data are given below.

TABLE I.

| Ref. No. | Efflux times (secs.) for 50 c.c. of oil at 70° F. | 100° F. | 140° F. | 160° F. | 180° F. | 210° F. |
|---|---|---|---|---|---|---|
| 1 | 158 | 84 | 51 | 44 | 40 | 35 |
| 2 | 182 | 90 | 53 | 44 | 40 | 36 |
| 3 | 325 | 140 | 68 | 52 | 45 | 38 |
| 4 | 379 | 165 | 77 | 58 | 49 | 42 |
| 5 | 528 | 215 | 86 | 61 | 50·5 | 42 |
| 6 | 543 | 213 | 87 | 62 | 51 | 42 |
| 7 | 749 | 283 | 107 | 71 | 57 | 46 |
| 8 | 962 | 333 | 120 | 80 | 60·5 | 48 |
| 9 | 1110 | 397 | 140 | 92 | 70 | 52 |
| 10 | 1267 | 419 | 140 | 87 | 67 | 50 |
| 11 | 4367 | 1304 | 405 | 266 | 174 | 99 |

The kinematic viscosities corresponding to the efflux times of all eleven oils at 70°, 140° and 210° F. were obtained from tables (see Note IV.) and three values of the constant n were then calculated. Using the mean of these the constant c (log w) was obtained. These mean values were then used to give the kinematic viscosities of the oils at the six temperatures in question and the equivalent Redwood times determined, again from tables. The mean values

of the constants, and the mean deviations from these means, are shown below :—

TABLE II.

| Ref. No. | Value of n. Mean. | Mean Deviation. Numerical. | % | Value of c (log w). Mean. | Mean Deviation. Numerical. | % |
|---|---|---|---|---|---|---|
| 1 | —2·060 | 0·037 | 1·80 | 3·4089 | 0·0053 | 0·16 |
| 2 | —2·093 | 0·032 | 1·53 | 3·5217 | 0·0046 | 0·13 |
| 3 | —2·510 | 0·033 | 1·31 | 4·5605 | 0·0047 | 0·10 |
| 4 | —2·415 | 0·038 | 1·57 | 4·4413 | 0·0055 | 0·12 |
| 5 | —2·722 | 0·021 | 0·77 | 5·1553 | 0·0030 | 0·06 |
| 6 | —2·750 | 0·016 | 0·58 | 5·2203 | 0·0023 | 0·04 |
| 7 | —2·877 | 0·011 | 0·38 | 5·5956 | 0·0017 | 0·02 |
| 8 | —3·027 | 0·034 | 1·12 | 5·9774 | 0·0049 | 0·08 |
| 9 | —3·041 | 0·004 | 0·13 | 6·0716 | 0·0006 | 0·01 |
| 10 | —3·217 | 0·008 | 0·25 | 6·4517 | 0·0011 | 0·02 |
| 11 | —3·528 | 0·073 | 2·07 | 7·5766 | 0·0104 | 0·14 |

The mean deviations average 0·028 (1·05 per cent.) and 0·0040 (0·08 per cent.) for n and c respectively, which are rather less than half of the averages found for the data considered in the preceding Note. The calculated Redwood efflux times are shown in table III., and the differences between observed and calculated times, expressed as percentages of the former, in table IV., below.

TABLE III.

| Ref. No. | Calculated Efflux Time (secs.) at 70° F. | 100° F. | 140° F. | 160° F. | 180° F. | 210° F. |
|---|---|---|---|---|---|---|
| 1 | 160·0 | 82·8 | 50·5 | 43·6 | 39·1 | 35·0 |
| 2 | 179·4 | 90·6 | 53·5 | 45·6 | 40·6 | 36·0 |
| 3 | 328·9 | 138·3 | 67·2 | 53·4 | 45·0 | 38·0 |
| 4 | 373·7 | 161·2 | 78·1 | 61·3 | 50·9 | 41·9 |
| 5 | 523· | 201·1 | 86·7 | 65·2 | 52·5 | 42·0 |
| 6 | 540· | 205·2 | 87·6 | 65·5 | 52·8 | 42·0 |
| 7 | 746· | 269·5 | 107·5 | 77·6 | 61·2 | 46·0 |
| 8 | 950· | 324·3 | 121·8 | 85·5 | 64·7 | 47·9 |
| 9 | 1112· | 377·2 | 139·6 | 96·7 | 72·0 | 52·0 |
| 10 | 1262· | 402·2 | 140·4 | 95·3 | 69·9 | 50·0 |
| 11 | 4485· | 1276· | 390·7 | 245·7 | 164·3 | 99·7 |

TABLE IV.

| Ref. No. | Percentage Difference between Observed and Calculated Times at (a) 70° F. | 100° F. | 140° F. | 160° F. | 180° F. | 210° F. |
|---|---|---|---|---|---|---|
| 1 | —1·3 | +1·4 | +1·0 | +0·9 | +2·2 | Nil |
| 2 | +1·4 | —0·7 | —0·9 | —3·6 | —1·5 | Nil |
| 3 | —1·2 | +1·2 | +1·2 | —2·6 | Nil | Nil |
| 4 | +1·4 | +2·3 | —1·4 | —5·7 | —3·9 | +0·2 |
| 5 | +1·0 | +6·5 | —0·8 | —6·9 | —3·9 | Nil |
| 6 | +0·6 | +3·7 | —0·7 | —5·6 | —3·5 | Nil |
| 7 | +0·4 | +4·7 | —0·5 | —9·3 | —7·3 | Nil |
| 8 | +1·2 | +2·6 | —1·5 | —6·9 | —6·9 | +0·2 |
| 9 | —0·2 | +5·0 | +0·3 | —5·1 | —2·8 | Nil |
| 10 | +0·4 | +4·0 | —0·3 | —9·5 | —4·3 | Nil |
| 11 | —2·7 | +2·2 | +3·5 | +7·6 | +5·6 | —0·7 |

(a) Times above 500 secs. given to nearest integer only in Table III. and differences calculated on this basis.

From table IV. it will be seen that the greatest numerical percentage difference between observed and calculated results is 9·5 per cent., and the mean is almost exactly 2·5 per cent. This latter value agrees well with that found in the preceding Note in applying equation (2) to other data. The differences are positive in 27 cases and negative in 30, the agreement being exact in the remainder. The differences are less than 3 per cent. in 44 of the 66 results and exceed 5 per cent. in only 12 cases—*i.e.*, less than one-fifth of the whole. The actual numerical differences are under 2 seconds in 37 instances and under 3 seconds in 44.

The differences between the calculated and observed results are naturally smallest in respect of the efflux times at 70°, 140° and 210° F., since the values of the constants used were calculated from experimental data obtained at these temperatures. Closer agreement could, of course, have been secured by evaluating the constants n and c on a wider experimental basis, but this was specifically avoided in order to provide a reasonable test of equation (4). It will be noted that the differences are appreciably greater in respect of the data at 160° F. than elsewhere, and this suggests that the temperature control in this case may not have been adequate. If the data for this temperature are disregarded, the mean positive and negative errors are alike 2·2 per cent. Having regard to the facts that assumed values had necessarily to be employed for the instrumental constants A and B, and that the data employed were obtained under strictly normal laboratory conditions, it is submitted that the agreement found is reasonably satisfactory. The differences are, in the main, of a small order, and it will be shown in the following Note that they do not, in general, exceed those due to a variation of ± 1° F. in the temperature of the oils under test. It is accordingly concluded that the substantial accuracy of the main hypothesis has been demonstrated.

## Summary and Conclusions.

1. An equation has been derived relating efflux time and temperature in the case of the short-tube viscometers in commercial use.

2. This equation has been applied to eleven oils of widely different viscosities.

3. In general, calculated Redwood times agree with the observed to within 2·5 per cent.

4. Reasons are indicated for regarding some rather greater percentage differences as due to faulty temperature-control.

## III. The Effect of Temperature upon Viscosity and Redwood Times, and the Slopes of Viscosity Curves.

Considerable importance attaches to the change of viscosity of lubricating oils with temperature and some aspects of this may be considered in the light of Eckart's logarithmic relation.

$$\log V = n \log \theta + c \quad \ldots\ldots (1)$$

in which V denotes the kinematic viscosity at $\theta$ ° F., n and c being constants for each oil (cf. Note I.). Differentiation with respect to $\theta$ gives

$$\frac{dV}{d\theta} = \frac{nV}{\theta} \quad \ldots\ldots (2)$$

from which it is seen that the rate of change of kinematic viscosity with temperature is directly proportional to the kinematic viscosity divided by the temperature (° F.), the constant of proportionality being characteristic for each oil. As this constant is a negative quantity (cf. Note 1.) equation (2) correctly shows that viscosity falls as temperature rises. For many practical purposes the percentage change in viscosity (temperature coefficient of viscosity) per 1 ° F. is possibly rather more convenient and this is given by

$$\frac{dV}{d\theta} \times \frac{100}{V} = \frac{nV}{\theta} \times \frac{100}{V} = \frac{100n}{\theta} \quad \ldots\ldots (3)$$

Percentage changes in kinematic viscosity per 1 °F. at three temperatures are shown below for the eleven oils considered in the preceding Note (*cf.* tables 1 and 2, *loc. cit.*) and for 5 addititional oils (Nos. 12—16) having the constants shown in table 2, below.

Table 1.

| Ref. No. | Percentage change in kinematic viscosity per 1° F. at 70° F. | 140° F. | 210° F. |
|---|---|---|---|
| 1 | 2·9 | 1·5 | 1·0 |
| 2 | 3·0 | 1·5 | 1·0 |
| 3 | 3·6 | 1·8 | 1·2 |
| 4 | 3·5 | 1·7 | 1·2 |
| 5 | 3·9 | 1·9 | 1·3 |
| 6 | 3·9 | 2·0 | 1·3 |
| 7 | 4·1 | 2·0 | 1·4 |
| 8 | 4·3 | 2·2 | 1·4 |
| 9 | 4·3 | 2·2 | 1·4 |
| 10 | 4·6 | 2·3 | 1·5 |
| 11 | 5·0 | 2·5 | 1·7 |
| 12 | 5·1 | 2·6 | 1·7 |
| 13 | 5·1 | 2·5 | 1·7 |
| 14 | 5·1 | 2·5 | 1·7 |
| 15 | 5·0 | 2·5 | 1·7 |
| 16 | 5·0 | 2·5 | 1·7 |

The percentage changes in kinematic viscosity at 70° F. are closely comparable with those found by Higgins at 20° C. for a variety of oils (N.P.L. Collected Researches, Vol. XI, pp. 1-16).

TABLE 2.

| Ref. No. | Efflux times for 50 c.c. (Redwood viscometer) secs. 70° F. | 140° F. | 210° F. | Values of constants in equation (1). n | c |
|---|---|---|---|---|---|
| 12 | 2851 | 237 | 65·0 | —3·595 | 7·5052 |
| 13 | 2660 | 223 | 63·5 | —3·554 | 7·4009 |
| 14 | 2585 | 232 | 63·5 | —3·546 | 7·3749 |
| 15 | 2580 | 233 | 66·0 | —3·486 | 7·2585 |
| 16 | 2480 | 221 | 62·0 | —3·534 | 7·3333 |

The variation with temperature of the viscosities of lubricating oils is represented with only moderate accuracy by the customary graphs of Redwood efflux times against temperature and the practical difficulties involved in the construction of such curves from the rather scanty data usually available do not add to their usefulness. So long, however, as the Redwood viscometer retains its present position these curves, despite their shortcomings, are unlikely to be supplanted by true viscosity-temperature curves. It is accordingly of some practical interest to consider whether some numerical expression can be derived to give somewhat more precision to the much used terms " steepness " and " flatness " of slope.

It has already been shown (*cf.* preceding Note) that the relation between Redwood efflux times, in seconds (T) and temperature ($\theta$° F.) may be formulated with moderate exactness as

$$AT-B/T=W\theta^n \quad \ldots\ldots(4)$$

If time be plotted, as ordinate, against temperature, as abscissa, the slope of the curve at any point is given by the quantity $dT/d\theta$. Differentiating equation (4), we have

$$\left(A+\frac{B}{T^2}\right)\frac{dT}{d\theta}=Wn\theta^{n-1}=\frac{n}{\theta}\left(AT-\frac{B}{T}\right) \quad \ldots\ldots(5)$$

and so

$$\frac{dT}{d\theta}=\frac{nT}{\theta}\left(\frac{AT^2-B}{AT^2+B}\right) \quad \ldots\ldots(6)$$

It may be noted that, although still empirical, this expression is dimensionally correct and gives the slope in terms of seconds per 1° F., as conditions require.

Means of testing the adequacy of this expression are available from the data in the preceding Note and the following table shows the extent of the agreement between the observed and calculated slopes at 140° F. The observed slopes were read from large-scale curves constructed from data obtained at intervals of 20° F.

TABLE III.

| Ref. No. | Slopes of curves (seconds per 1° F.) at 140° F. Observed. | Calculated from equation (6). | Observed—calculated. |
|---|---|---|---|
| 1 | —0·45 | —0·45 | Nil |
| 2 | —0·52 | —0·49 | —0·03 |
| 3 | —0·92 | —0·92 | Nil |
| 4 | —1·13 | —1·06 | —0·07 |
| 5 | —1·50 | —1·40 | —0·10 |
| 6 | —1·58 | —1·44 | —0·14 |
| 7 | —2·24 | —1·96 | —0·28 |
| 8 | —2·41 | —2·37 | —0·04 |
| 9 | —3·09 | —2·84 | —0·25 |
| 10 | —3·38 | —3·01 | —0·37 |
| 11 | —9·84 | —10·13 | +0·29 |

The numerical average is 0·14 and the maximum difference 0·37 second per 1° F. The agreement appears reasonably satisfactory having regard, on the one hand, to the approximate basis of the calculations and, on the other, to the uncertainty attaching to the precise contour of the curves even with the experimental data available.

The following table gives the slopes for all the oils now in question at three temperatures commonly adopted for determinations of Redwood efflux times :—

TABLE IV.

| Ref. No. | Slopes (seconds per 1° F.) calculated in accordance with equation (6) at 70° F. | 140° F. (*a*) | 210° F. |
|---|---|---|---|
| 1 | —4·41 | —0·45 | —0·10 |
| 2 | —5·23 | —0·49 | —0·12 |
| 3 | —11·50 | —0·92 | —0·17 |
| 4 | —12·95 | —1·06 | —0·23 |
| 5 | —20·43 | —1·40 | —0·25 |
| 6 | —21·23 | —1·44 | —0·25 |
| 7 | —30·69 | —1·96 | —0·33 |
| 8 | —41·52 | —2·37 | —0·34 |
| 9 | —48·17 | —2·84 | —0·46 |
| 10 | —58·19 | —3·01 | —0·45 |
| 11 | —220·1 | —10·13 | —1·42 |
| 12 | —146·4 | —5·95 | —0·81 |
| 13 | —135·0 | —5·51 | —0·77 |
| 14 | —130·9 | —5·73 | —0·77 |
| 15 | —128·5 | —5·49 | —0·81 |
| 16 | —125·2 | —5·43 | —0·74 |

(*a*) Slopes for Nos. 1–11 reproduced from Table III.

Percentage variation per 1° F. in Redwood efflux time is not usually required, but it may readily be deduced that it is given by

$$\frac{100}{T} \times \frac{dT}{d\theta} = \frac{100n}{\theta} \times \frac{AT^2 - B}{AT^2 + B} \quad \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

The resemblance of this equation with (3), above, will be noted.

Somewhat laborious calculations are involved in applying equation (6) to any extensive series of data, and it appeared desirable to consider whether any approximate simplification was practicable. Adopting for the instrumental constants A and B the values found by Higgins (*loc. cit.*), it may readily be shown that the factor $\frac{AT^2 - B}{AT^2 + B}$ deviates from unity by less than 1 per cent. when the efflux time, T, is more than 365 seconds approximately. The error involved in taking this factor as unity increases rather rapidly with fall in efflux time, as the following table shows, and it will be evident that this approximation can hardly be employed, except when purely comparative figures will suffice, for values of T much below 250 seconds.

TABLE V.

| Efflux time secs. (T). | $\frac{AT^2-B}{AT^2+B}$ |
|---|---|
| 500 | 0·995 |
| 400 | 0·992 |
| 350 | 0·989 |
| 300 | 0·985 |
| 250 | 0·979 |
| 200 | 0·968 |
| 150 | 0·943 |

The relation formulated at (6), above, enables the slopes of the customary "viscosity" curves to be expressed numerically and so permits of more precise comparisons of oils in this respect than are possible by visual means alone. In addition, however, it provides certain indications regarding the accuracy attainable with the Redwood instrument. The data in table IV. show also what changes in the efflux times of the oils would result from changing the temperature of the determination by 1° F. As will be seen, these changes become greater as the temperature is reduced, and in the case of the more viscous oils they become sufficiently large to be of serious moment. It may be noted here that the differences between the calculated and observed efflux times at 70° F., 140° and 210° F. of the eleven oils considered in the previous Note (*cf.* tables I. and III., *loc. cit.*) are rarely substantially greater than would result from a variation of ± 1° F. in the temperature of determination. This is an index of the reliability of Eckart's relation.

The temperature co-efficients of viscosity of lubricating oils are so great that accurate determination of viscosity is a matter of real difficulty unless temperatures can be controlled with considerable precision and, from the structure of the Redwood viscometer, this is clearly not to be expected in commercial

viscometry (*cf.* Higgins, *loc. cit.*). It appears to be generally agreed that in technical laboratories results accurate to less than 1 per cent. will rarely be obtainable on this account alone, and it is therefore of interest to enquire within what limits of constancy temperatures must be maintained.

It has already been shown (eqn. (3), Note II.) that

$$V = W\theta^n \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

so that, differentiating,

$$dV = Wn\theta^{n-1}\, d\theta \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

If now, dV = 1 per cent. of V—*i.e.*, dV = 0·01V—it will be clear that

$$d\theta = \frac{0{\cdot}01\theta}{n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

The values of n (*cf.* Note II.) range from about −2·0 in the case of light spindle oils to −3·5 in the case of light cylinder oils and values up to about −5·0 have been found in other instances. Using these three values for n in the above equation we obtain :—

TABLE VI.

| Value of n. | Temperature of viscosity detn. (° F.) | Variation in temperature causing 1 per cent. change in viscosity. |
|---|---|---|
| −2·0 | 70 | 0·35° F. |
| | 140 | 0·70° F. |
| | 210 | 1·05° F. |
| −3·5 | 70 | 0·20° F. |
| | 140 | 0·40° F. |
| | 210 | 0·60° F. |
| −5·0 | 70 | 0·14° F. |
| | 140 | 0·28° F. |
| | 210 | 0·42° F. |

It will be clear that, the more viscous the type of oil, the more rigorously must the temperature be controlled, and that variations of less than one-fifth of 1° F. may on occasion be serious. The conclusion that control of temperature is relatively most important when temperatures of determination are low is in agreement with practical experience that discordant results are most likely and most serious at low temperatures.

Combination of equations (6) and (10) leads to—

$$dT = \frac{T}{100} \times \frac{AT^2 - B}{AT^2 + B} \quad \ldots\ldots\ldots\ldots\ldots\ldots (11)$$

from which may be calculated the change in Redwood efflux time equivalent to a change of 1 per cent. in viscosity—*e.g.*, due to

the temperature variations shown in the preceding table. It will be noted that this change is independent of the characteristic constants of the oils.

TABLE VII.

| Efflux time T (secs.). | Change in Redwood time equivalent to a change of 1 per cent. in viscosity (dT). | Efflux time T (secs.). | Change in Redwood time equivalent to a change of 1 per cent. in viscosity (dT). |
|---|---|---|---|
| 40 | 0·17 sec. | 300 | 2·96 sec. |
| 50 | 0·29 | 400 | 3·97 |
| 60 | 0·41 | 500 | 4·98 |
| 70 | 0·53 | 600 | 5·99 |
| 80 | 0·65 | 700 | 7·00 |
| 90 | 0·77 | 800 | 8·00 |
| 100 | 0·88 | 900 | 9·00 |
| 120 | 1·09 | 1000 | 10·00 |
| 140 | 1·30 | 1200 | 12·00 |
| 160 | 1·52 | 1400 | 14·00 |
| 180 | 1·73 | 1600 | 16·00 |
| 200 | 1·94 | 1800 | 18·00 |
| 250 | 2·45 | 2000 | 20·00 |

It will be clear that with the less viscous oils at all temperatures, and with the more viscous at higher temperatures, numerically small differences in Redwood efflux times denote appreciable differences in viscosity. The foregoing table may incidentally find some application in assessing the importance to be attached to differences between repeat determinations made on particular instruments.

## SUMMARY AND CONCLUSIONS.

1. Eckart's logarithmic relation leads to values for the temperature coefficient of viscosity of lubricating oils in good agreement with those actually found.

2. The slopes of the actual Redwood-seconds-temperature curves of eleven oils studied have been found to be in close agreement with those calculated on the basis of Eckart's relation.

3. The slopes of lubricating oils of widely different types have been calculated at three temperatures.

4. An approximate method for calculating slopes for oils of Redwood times in excess of 250 seconds is indicated.

5. Control of temperature in determination of Redwood efflux times is discussed and deviations affecting kinematic viscosities by 1 per cent. are calculated for three particular cases.

6. The effects of 1 per cent. change in kinematic viscosity (due to alteration in temperature) upon Redwood efflux times are calculated for efflux times ranging from 40 to 2000 seconds.

## IV. Conversion Tables for Redwood Seconds and Kinematic Viscosities.

The calculations required when Eckart's logarithmic relation is employed are greatly simplified if suitable conversion tables are available. The table appended has been found satisfactory in extended use and admits of interpolation with a sufficient degree of accuracy. It is based upon the equation and instrumental constants found by Higgins (N.P.L. Collected Researches, Vol. XI., pp. 1—16), viz.:—

$$V=0{\cdot}0026T-1{\cdot}715/T \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

in which V denotes the kinematic viscosity corresponding to an efflux time of T seconds.

The appended table naturally applies strictly only to viscometers with the constants stated, and since Redwood instruments as a whole may vary considerably it is desirable that the constants should be carefully evaluated for each individual instrument in use. This may conveniently be done by means of liquids of known viscosity for which the Redwood efflux times lie preferably between 50 and 1000 seconds (*cf.* also British Standard Specification No. 188—1929, The Determination of Viscosity in Absolute Units).

Even if the constants so found deviate from those used above, the table may still be employed subject to the application of appropriate corrections. These may be found as follows:

Let the constants for a particular instrument, determined as above, be L and M. Then the kinematic viscosity, X, corresponding to an efflux time of T seconds, will be given by

$$X=LT-M/T \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

For this efflux time in a standard instrument, however, the table gives a value V for the kinematic viscosity, calculated in accordance with equation (1). For the particular instrument in question, therefore, the correction to be added to the tabulated value, V, will be X—V. From equations (1) and (2) we have

$$X-V=(L-0{\cdot}0026)T-(M-1{\cdot}715)/T \quad \ldots\ldots\ldots\ldots\ldots (3)$$

Since L and M are assumed to be known the correction term is readily evaluated. An example may assist in making the calculation clear. If, for a particular instrument L=0·0020 and M=1·60,

then an efflux time of 100 seconds corresponds to a kinematic viscosity of $X=(100\times0{\cdot}0020)-(1{\cdot}60\div100)=0{\cdot}184$
From the table, against T=100 seconds we have a kinematic viscosity of 0·2428. To this the correction to be applied is, by equation (3).

$$100\ (0{\cdot}0020-0{\cdot}0026)-(1{\cdot}60-1{\cdot}715)/100$$

*i.e.*, $-0{\cdot}0600+0{\cdot}0012=-0{\cdot}0588$.
Whence 0·2428—0·0588=0·184, the required value.

Where M differs only slightly from 1·715 or T is large (above, say, 250 seconds) the second term becomes vanishingly small and the correction is accordingly simplified.

Oils may be compared on the basis of kinematic viscosities when they are closely similar in density, but when the densities differ considerably calculation of absolute viscosities is practically essential. Absolute viscosity, A, is related to kinematic viscosity, V, by the equation

$$\frac{A}{D}=V \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

n which D denotes the density of the oil.

It will be apparent that, for liquids lighter than water, the kinematic viscosity is always greater than the absolute viscosity. In the case of lubricating oils the specific gravity at one temperature is usually sufficient for technical purposes, and when this is the only information available densities at other temperatures must be calculated, in the usual manner, on the assumption that specific gravity changes by 0·00034 per 1° F. It should, however, be emphasised that only approximate values can be arrived at in this way and that where any degree of precision is required densities should be determined with the necessary precautions, an accuracy of 0·0002 being desirable.

## Summary.

1. A table (appended) has been prepared relating Redwood efflux times and kinematic viscosities in the case of viscometers identical with that used by Higgins.

2. A correction formula is derived which enables this table to be employed for viscometers possessing different constants.

3. Conditions which make it necessary to employ absolute viscosities are indicated and notes on the calculation of absolute viscosities are added.

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Royal Arsenal, Woolwich.

| Red-wood time (secs.). | Kine-matic viscosity. | Log. of 100× kinematic viscosity. | Red-wood time (secs.). | Kine-matic viscosity. | Log. of 100× kinematic viscosity. |
|---|---|---|---|---|---|
| 2500 | 6·4993 | 2·81287 | 420 | 1·0879 | 2·03659 |
| 2400 | 6·2393 | 2·79513 | 410 | 1·0618 | 2·02604 |
| 2300 | 5·9793 | 2·77665 | 400 | 1·0357 | 2·01523 |
| 2200 | 5·7193 | 2·75734 | 390 | 1·0096 | 2·00405 |
| 2100 | 5·4592 | 2·73713 | 380 | 0·9835 | 1·99277 |
| 2000 | 5·1991 | 2·71593 | 270 | 0·9574 | 1·98109 |
| 1900 | 4·9391 | 2·69365 | 360 | 0·9312 | 1·96904 |
| 1800 | 4·6790 | 2·67015 | 350 | 0·9051 | 1·95670 |
| 1700 | 4·4190 | 2·64532 | 340 | 0·8790 | 1·94399 |
| 1600 | 4·1589 | 2·61898 | 330 | 0·8528 | 1·93085 |
| 1500 | 3·8989 | 2·59094 | 320 | 0·8267 | 1·91735 |
| 1450 | 3·7688 | 2·57621 | 310 | 0·8005 | 1·90336 |
| 1400 | 3·6388 | 2·56096 | 300 | 0·7743 | 1·88891 |
| 1350 | 3·5087 | 2·54514 | 290 | 0·7481 | 1·87396 |
| 1300 | 3·3787 | 2·52875 | 280 | 0·7219 | 1·85848 |
| 1250 | 3·2486 | 2·51170 | 270 | 0·6957 | 1·84242 |
| 1200 | 3·1186 | 2·49396 | 260 | 0·6694 | 1·82569 |
| 1150 | 2·9885 | 2·47545 | 250 | 0·6431 | 1·80828 |
| 1100 | 2·8584 | 2·45612 | 240 | 0·6169 | 1·79021 |
| 1050 | 2·7283 | 2·43589 | 230 | 0·5905 | 1·77122 |
| 1000 | 2·5983 | 2·41469 | 220 | 0·5642 | 1·75143 |
| 975 | 2·5332 | 2·40367 | 210 | 0·5378 | 1·73062 |
| 950 | 2·4682 | 2·39237 | 200 | 0·5114 | 1·70876 |
| 925 | 2·4031 | 2·38077 | 195 | 0·4982 | 1·69740 |
| 900 | 2·3381 | 2·36886 | 190 | 0·4850 | 1·68574 |
| 875 | 2·2731 | 2·35662 | 185 | 0·4717 | 1·67367 |
| 850 | 2·2080 | 2·34400 | 180 | 0·4585 | 1·66134 |
| 825 | 2·1429 | 2·33100 | 175 | 0·4452 | 1·64856 |
| 800 | 2·0779 | 2·31763 | 170 | 0·4319 | 1·63538 |
| 775 | 2·0128 | 2·30381 | 165 | 0·4186 | 1·62180 |
| 750 | 1·9477 | 2·28952 | 160 | 0·4053 | 1·60778 |
| 725 | 1·8826 | 2·27476 | 155 | 0·3919 | 1·59318 |
| 700 | 1·8175 | 2·25947 | 150 | 0·3786 | 1·57818 |
| 675 | 1·7524 | 2·24363 | 145 | 0·3653 | 1·56265 |
| 650 | 1·6874 | 2·22723 | 140 | 0·3518 | 1·54630 |
| 625 | 1·6223 | 2·21013 | 135 | 0·3383 | 1·52930 |
| 600 | 1·5571 | 2·19232 | 130 | 0·3248 | 1·51162 |
| 575 | 1·4920 | 2·17377 | 125 | 0·3113 | 1·49318 |
| 550 | 1·4269 | 2·15439 | 120 | 0·2977 | 1·47378 |
| 525 | 1·3617 | 2·13408 | 115 | 0·2841 | 1·45347 |
| 500 | 1·2966 | 2·11281 | 110 | 0·2704 | 1·43201 |
| 490 | 1·2705 | 2·10397 | 105 | 0·2567 | 1·40943 |
| 480 | 1·2444 | 2·09496 | 100 | 0·2428 | 1·38525 |
| 470 | 1·2183 | 2·08576 | 98 | 0·2373 | 1·37530 |
| 460 | 1·1923 | 2·07639 | 96 | 0·2317 | 1·36493 |
| 450 | 1·1662 | 2·06677 | 95 | 0·2289 | 1·35965 |
| 440 | 1·1401 | 2·05694 | 94 | 0·2262 | 1·35449 |
| 430 | 1·1140 | 2·04689 | 92 | 0·2206 | 1·34361 |

| Red-wood time (secs.). | Kine-matic viscosity. | Log. of 100 × kinematic viscosity. | Red-wood time (secs.). | Kine-matic viscosity. | Log. of 100 × kinematic viscosity. |
|---|---|---|---|---|---|
| 90 | 0·2149 | 1·33224 | 53 | 0·1054 | 1·02284 |
| 88 | 0·2093 | 1·32077 | 52 | 0·1022 | 1·00945 |
| 86 | 0·2037 | 1·30899 | 51 | 0·0990 | 0·99564 |
| 85 | 0·2008 | 1·30276 | 50 | 0·0957 | 0·98091 |
| 84 | 0·1980 | 1·29667 | 49 | 0·0924 | 0·96567 |
| 82 | 0·1923 | 1·28398 | 48 | 0·0891 | 0·94988 |
| 80 | 0·1866 | 1·27091 | 47 | 0·0857 | 0·93298 |
| 78 | 0·1808 | 1·25720 | 46 | 0·0823 | 0·91540 |
| 76 | 0·1750 | 1·24304 | 45 | 0·0789 | 0·89708 |
| 75 | 0·1721 | 1·23578 | 44 | 0·0754 | 0·87737 |
| 74 | 0·1692 | 1·22840 | 43 | 0·0719 | 0·85673 |
| 72 | 0·1634 | 1·21325 | 42 | 0·0684 | 0·83506 |
| 70 | 0·1575 | 1·19728 | 41 | 0·0648 | 0·81158 |
| 68 | 0·1516 | 1·18070 | 40 | 0·0611 | 0·78604 |
| 66 | 0·1456 | 1·16316 | 39 | 0·0574 | 0·75891 |
| 65 | 0·1426 | 1·15412 | 38 | 0·0537 | 0·72997 |
| 64 | 0·1396 | 1·14489 | 37 | 0·0499 | 0·69810 |
| 62 | 0·1335 | 1·12548 | 36 | 0·0460 | 0·66276 |
| 60 | 0·1274 | 1·10517 | 35 | 0·0420 | 0·62325 |
| 59 | 0·1243 | 1·09447 | 34 | 0·0380 | 0·57978 |
| 58 | 0·1212 | 1·08350 | 33 | 0·0338 | 0·52892 |
| 57 | 0·1181 | 1·07225 | 32 | 0·0296 | 0·47129 |
| 56 | 0·1150 | 1·06070 | 31 | 0·0253 | 0·40312 |
| 55 | 0·1118 | 1·04844 | 30 | 0·0208 | 0·31806 |
| 54 | 0·1086 | 1·03583 | | | |

## Cracking of Rangoon Paraffin in Vapour Phase.[1]

By J. W. Heymans.[2]

*Introduction.*—The experiments to be described have for their object the study of the decomposition of hydrocarbons, when this decomposition occurs in a vacuum sufficient to obtain the raw material in vapour phase.

The cracking of hydrocarbons in liquid phase has already been studied by many investigators,[3] and it was desired to discover if and how far the vapour-phase cracking process differs from this.

*Material Employed.*—The material used was the so-called Rangoon paraffin, the properties of which are as follows :—

| | |
|---|---|
| Specific gravity (60° C./4° C.) .. .. .. | 0·784 |
| Melting point (Shukoff) .. .. .. .. | 58° C. |
| Refraction 60° C. (Abbe) .. .. .. .. | 1·4375 |
| Average molecular weight (Rast)[4] .. .. .. | 407 |
| Bromine value (McIlhiney) .. .. .. .. | 0 % of weight |

*Apparatus Employed* (Fig. 1).—The paraffin is placed in the funnel, A, where it is kept liquid by an electrically heated nickel-chrome spiral. From there it flows into the iron tube, B, C, D, filled with broken glass tubing, which serves as filling material to keep the temperature as uniform as possible. The iron tube is in an electrical oven and is thus maintained at a high temperature. The temperature is indicated by a thermo-electrical couple placed midway in the iron tube, and the readings are taken on the millivoltmeter $T_1$.

The gases formed first undergo fractional condensation in the first condenser, which is kept at a temperature of 200° C. by the circulation of heated castor oil, then in a water condenser, and further in the condensers G, H, I, surrounded respectively with ice and HCl, solid $CO_2$ and alcohol, and liquid air. In E the heavy fraction is obtained, in F the light fraction, and in G, H, I the volatile products and the condensable gases. The permanent gases formed pass through the vacuum pump and are not retained. The pressure in the apparatus is measured by the manometer M.

Sometimes in E the paraffin forms a mist and solid particles are carried with the gases and obstruct the apparatus further on. For that reason a small glass bulb, containing cotton-wool, is placed in $E^1$ to retain the solid particles. Further the tube B, C, D must be cooled at the ends to prevent the burning of the corks.

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[1] Study made under the direction of Prof. Dr. Ing. H. I. Waterman in his Laboratory for Chemical Technology of the Technical University of Delft. Paper received June 2, 1930.

[2] University of Ghent, Ghent, Belgium.

[3] *E.g.*, H. I. Waterman and J. N. J. Perquin, *J. Inst. Petr. Techn.*, 1925, **11**, 36; H. I. Waterman and T. W. Te Nuyl and J. N. J. Perquin, idem., 1929. **15**, 369.

[4] Rast, *Ber.*, 1922, **55** (1), 1051; H. I. Waterman, J. N. J. Perquin and H. A. van Westen, *J. Inst. Petr. Techn.*, 1928, **14**, 318.

*Experimental Method.*—First the oven and the first condenser are brought to the required temperature, and, when this has been regulated, the vacuum pump is started; then Dewar beakers are placed under the condensers G, H, I. Finally, the paraffin is introduced in drops so as to insure regularity. To avoid the solidification of the paraffin in the tap a and the connection b, a is wound with copper wire, the projecting end of which is warmed with a small Bunsen burner, whilst b is covered with asbestos cord and also, if necessary, warmed with a small flame. The regulation of the paraffin flow is the most difficult part of the experiment.

When the experiment is finished the condensed gases in H and I are liberated and collected under salt water; the funnel A, the receivers E and F, and the condensers G, H, I are weighed. The differences between these weights and those obtained before the experiment give the quantity of material employed and of the various non-volatile products obtained.

After the cooling down of the oven the tube is withdrawn. There is always a small quantity of unchanged paraffin left in the tube at B. The loss of weight of the funnel A, less the quantity at B, gives the actual amount of material consumed. Moreover, at D is found a certain quantity of condensed product that strictly belongs to the product E and to which it is added before the analysis, as is also the product obtained at $E^1$. Then the filling material in the tube is washed with $CCl_4$ to remove all remaining products, the solvent evaporated and the product C obtained.

Thus we have :—

A—B gives the quantity of material employed (A=loss of weight of the funnel A).

C is the quantity of fixed product remaining in the tube.

$D+E+E^1$ is the heavy products.

F is the light products.

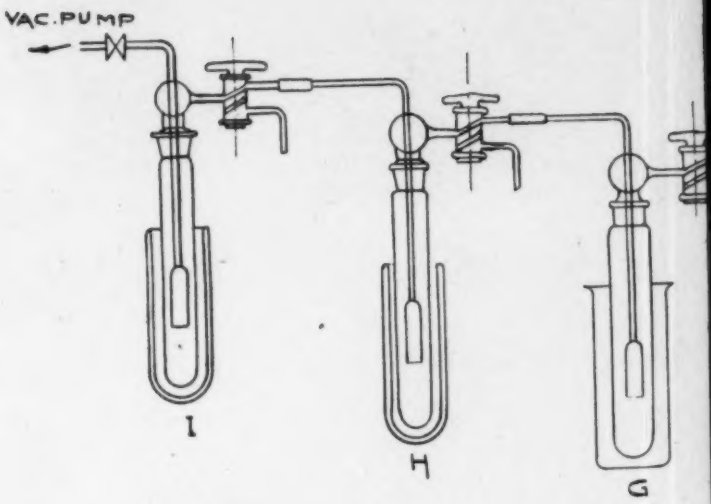
$C+H+I_1$ is the lightest liquid products.

$I_2$ is the condensed gases (calculated from their volume and spec. grav.).

$(A-B)-(C+D+E+E^1+F+G+H+I_1+I_2)$ is the quantity of permanent gases formed plus loss.

*Examination of the Products Obtained.*—All these products are now examined to discover what changes the paraffin undergoes during the cracking. For example, the specific gravity (60° C./4° C.), the melting point (Shukoff), the refraction $n^D$ 60° (Abbe), the bromine value, and the molecular weight of the products C and $D+E+E^1$ are determined.

The product F has not been obtained in any of our experiments as the gases pass so rapidly through the apparatus that the small


VAC. PUMP
I
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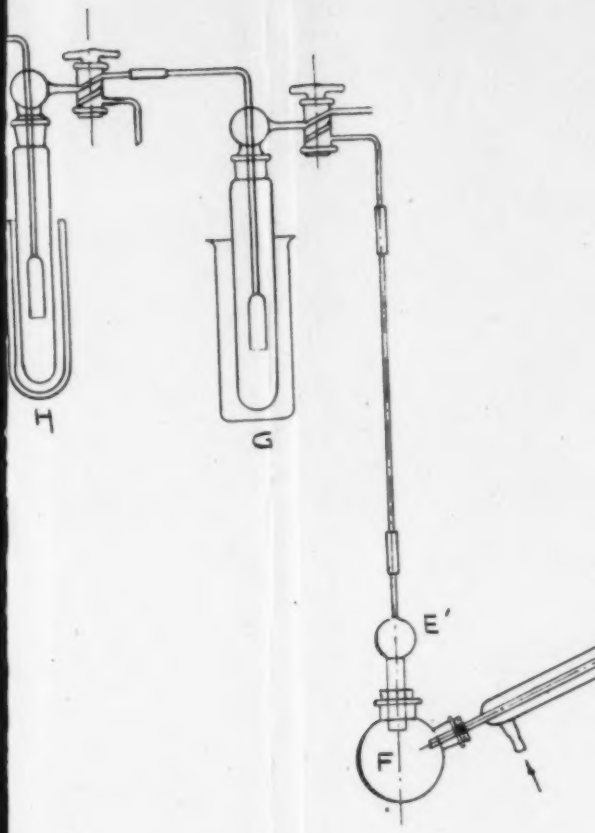
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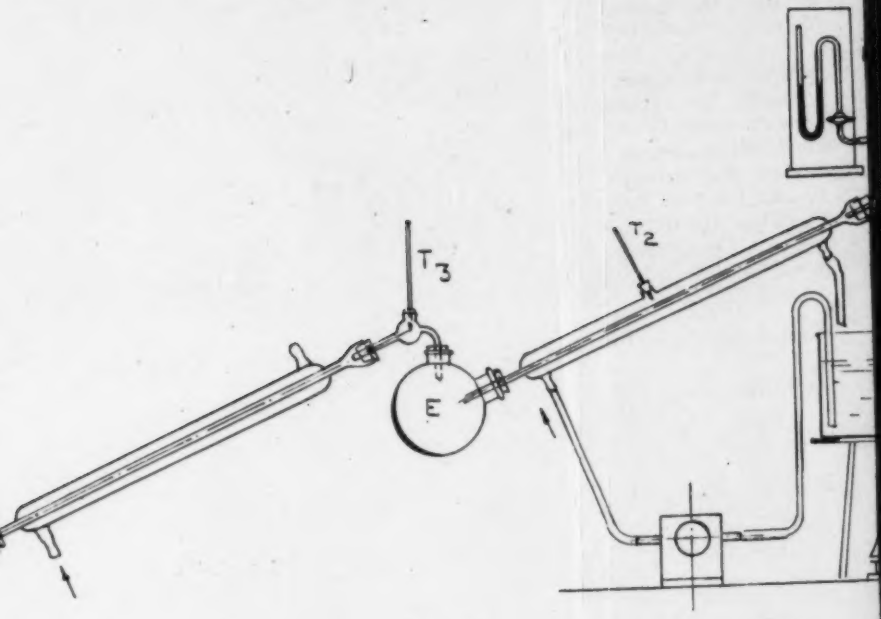



Fig. 1.

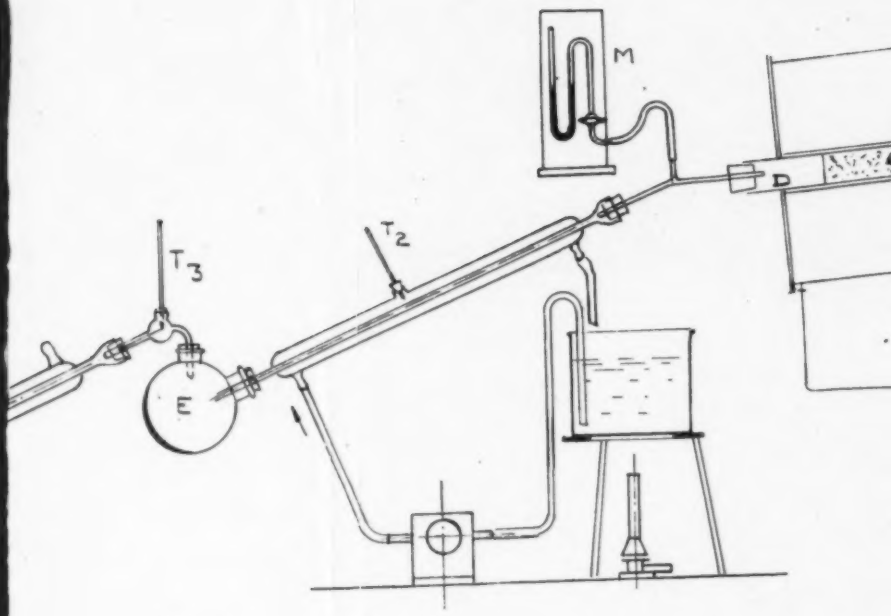
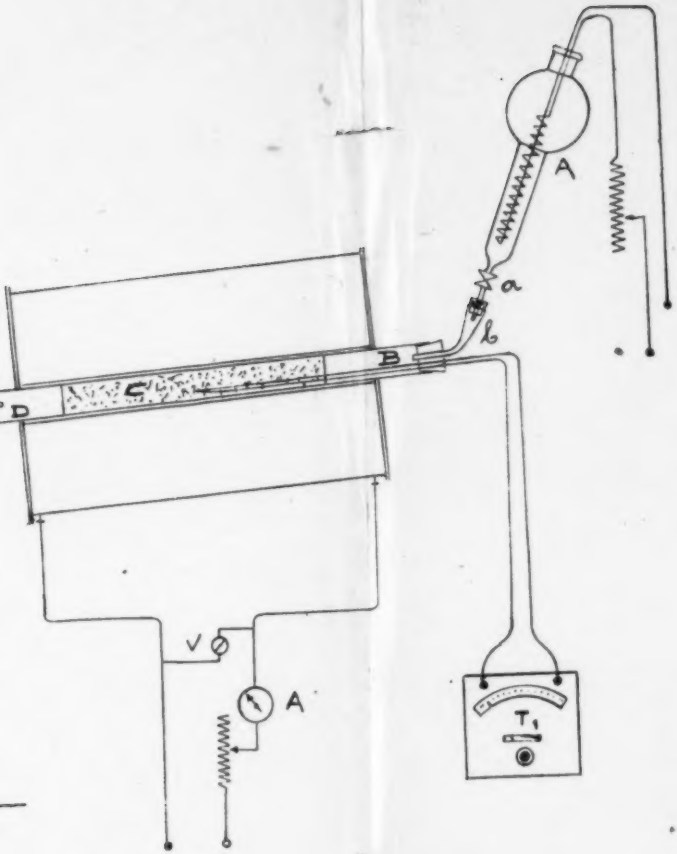



FIG. 1.


A
a
b
B
C
D
V
A
T1

quantities of the lightest liquid products that are formed cannot condense in the water condenser. This product, denoted by H and $I_1$, was caught in the condensers H and I. The specific gravity (20° C./4° C.) of the product $H+I_1$ was determined, as well as the refraction (20° C.) and the bromine value. The molecular weight could not be determined on account of the small quantity obtained. For this molecular weight the average number 75 ($C_5H_{12}$—$C_6H_6$—$C_6H_{14}$) has been taken.

The analysis of the condensable gases $I_2$ was performed in the following way :—

Absorption with KOH to determine the percentage of $CO_2$
" " $H_2SO_4$ (87%) to determine the percentage of $C_2H_4$ and hom.
" " $Hg(NO_3)_2$ sat. with $NaNO_3$ to determine the percentage of $C_2H_4$
" " bromine water to determine the percentage of $C_6H_6$
" " pyrogall-potash to determine the percentage of $O_2$
" " ammen, $Cu_2Cl_2$ to determine the percentage of CO
Combustion at 270° C. to determine the percentage of $H_2$
" " a high temperature to determine the percentage of $CH_4$ and hom.

The specific gravity of the gases and the weight of a litre (0° C.—760 mm.) was determined by the Chancel method, and was checked by that calculated from the analysis. The calculation gives two values, the first being obtained by assuming that the product absorbed by $H_2SO_4$ (87 per cent.) is only $C_2H_6$ and not the homologues, and that the product oxidised at a high temperature is only $CH_4$. The second value is obtained by assuming that both these products are homologues. The determined value for the specific gravity should lie probably between these two figures.

The bromine value of these gases can also be calculated from the analysis. It is known in fact that a gram molecule of unsaturated hydrocarbon (*i.e.*, ± 22·4 l.) absorbs 160 gram of bromine. Since the volume and the weight of these gases is known, as well as percentage of unsaturated hydrocarbons, it is possible to calculate how much bromine will be absorbed by 100 gram of the gases.

For the permanent gases, which escape, a molecular weight of 10 is assumed. These gases consist of a mixture of $H_2$ and $CH_4$ and the results of an analysis show that the percentages of $H_2$ and $CH_4$ are approximately equal.

The results of these experiments were set down in tabular form, and in order more easily to draw the necessary conclusions a second table is given relating to one gram molecule of paraffin (407 gram).

This Table gives :—

1. The quantity in grams of the different products C, D+E+$E^1$, etc., derived from 1 gram molecule paraffin (407 gr.).

2. The molecular weight of these products (taken from Table I.).

3. The amount of gram molecules of these products (calculated from 1 and 2).

The sum of these numbers gives the total amount of gram molecules obtained from 1 gram molecule of paraffin, and is therefore a measure of the decomposition.

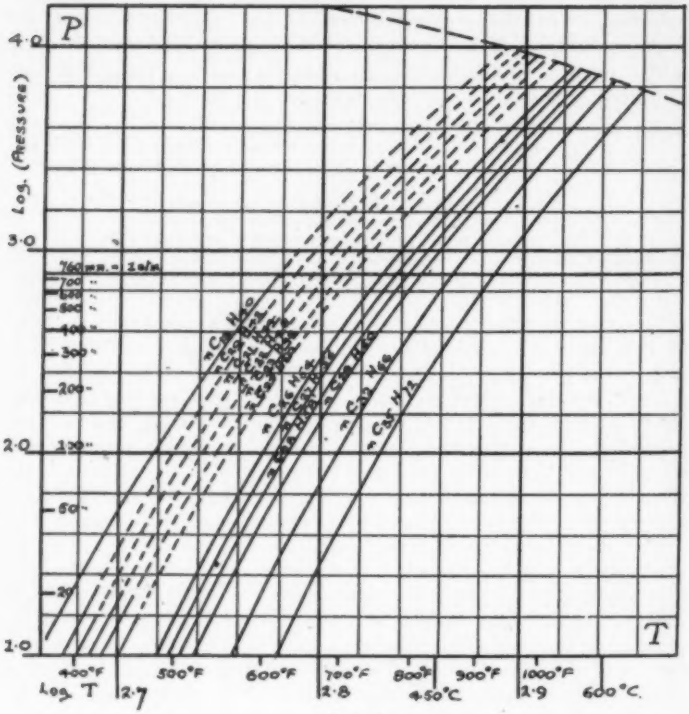



FIG. 2.

4. The quantity of bromine absorbed by addition (calculated from 1 and the bromine value).

5. The quantity of gram molecules of unsaturated hydrocarbons present in these products (calculated from 4, assuming that each unsaturated molecule has only one double link. Then 1 gram molecule unsaturated takes up 160 gr. of bromine by addition).

6. The percentage of unsaturated bodies: this is the quantity of unsaturateds in 100 molecules of the different products (calculated from 3 and 5).

These last figures give a good idea of the quantity of unsaturated bodies and how they are distributed among the different products.

Before considering the results of the experiments it must be proved that, at the temperature and the pressure obtained in our apparatus, all the raw material remained in the vapour phase.

Therefore the graphs P/T, given by R. E. Wilson and W. H. Bahle,[5] for the normal hydrocarbons up to $C_{24}H_{58}$ are extended to $C_{35}H_{72}$ (Fig. 2), to see if those obtained agree with the boiling points given in Beilstein. From Fig. 2 it will be seen that, if $C_{35}H_{72}$ is taken as highest hydrocarbon in the Rangoon paraffin, it remains entirely in the vapour phase at 450° C. if the pressure is lower than 300 mm. Hg. A lower pressure than 300 mm. and a higher temperature than 450° C. assures that the paraffin is completely in the vapour phase.

*Experiment I.*—$T_1$ : cracking temperature : 450° C.

M : pressure in the apparatus : 10 mm. (max.).

Rate of introduction of the paraffin : 1 drop per 2 seconds.

From this last figure and the specific gravity and the molecular weight of the paraffin it can be calculated how many litres of gases are formed per second in the apparatus (at 450° C. and 10 mm. pressure) = V.

If it is assumed that the length of the iron tube that is at 450° C. is equal to the length filled with broken glass tubing, the volume of the tube which is at this temperature can be calculated = $V_1$.

$\frac{V_1}{V}$ thus gives the time during which each part of the paraffin remains in vapour phase at the temperature of the experiment.

This calculation gives for this experiment : 1·7 sec.

TABLE I. (EXPERIMENT 1).

*Material Employed.*

A − B = 101·5 − 0·5 = 101 gr.

| | *Products Obtained.* | Weight. in grs. | % | S.g. 60° 4° C. | Bromine number in w. % | Bromine number in grs. | Melt. point. | Refr. 60°C. | Mol. w. |
|---|---|---|---|---|---|---|---|---|---|
| C | Solid | 3·5 | 3·5 | — | 1·4 | 0·05 | 55·6 | 1·4393 | 527 |
| D | ,, | 5·0 | 4·9 | | | | | | |
| E | ,, | 89·0 | 88·1 | 0·7851 | 1·3 | 1·23 | 57·8 | 1·4385 | 405 |
| $E^1$ | ,, | 0·5 | 0·5 | | | | | | |
| F | — | — | — | — | — | — | — | — | — |
| G | Water | — | — | — | — | — | — | — | — |
| H | ,, | — | — | — | — | — | — | — | — |
| I | Gas and loss | 3·0 | 3·0 | Cond. gas. S.G./air(1) = 1·3–1·4 | 30·0 | 0·06 | | | Cond. g. ±40 (1) |
| | | 101·0 | 100·0 | | | | | | |
| | Rangoon-Paraffin | | | 0·784 | 0·0 | 0·00 | 58° C. | 1·4375 | 407 |

[5] *Ind. Eng. Chem.*, 1924, **16**, 115.

(1) Calculated from the analysis :—

| | |
|---|---|
| $CO_2$ .. .. .. .. .. .. | 69·4 per cent. |
| $C_2H_4$ and hom. .. .. .. .. | 3·7 ,, |
| $C_2H_6$ .. .. .. .. .. .. | 4·3 ,, |
| $C_6H_6$ .. .. .. .. .. .. | 0·0 ,, |
| $O_2$ .. .. .. .. .. .. | 0·4 ,, |
| CO .. .. .. .. .. .. | 0·6 ,, |
| $H_2$ .. .. .. .. .. .. | 0·0 ,, |
| $CH_4$ and hom. .. .. .. .. | 16·6 ,, |
| | 95·5 ,, |

The volume of the cond. gases obtained = 110 c.c.

## TABLE II. (EXPERIMENT 1).

1 gram molecule of paraffin (407 gr.) gives :—

| | C. | D+E+E¹. | Tot. gas + loss. | Total. |
|---|---|---|---|---|
| Quant. in grs. .. .. .. | 14·2 | 380·0 | 12·8 | 407·0 |
| Mol. weight .. .. .. | 527·0 | 405·0 | 10·5 (1) | — |
| Amount of gr. mol. .. .. | 0·027 | 0·94 | 1·2 | 2·1 |
| Bromine abs. by add. .. .. | 0·2 | 4·95 | 0·25 | 5·35 |
| Quant. of gr. mol. of unsaturated | 0·0012 | 0·031 | 0·0015 | 0·034 |
| Percentage of unsat. bod. .. | 4–5% | 3–4% | 0·1% | 0·14% |

(1) 1 lit. gas (0°–760 mm.) = 1·35 × 1·29 = 1·7415 gr. (1·35 = s.g. of the cond. gases) (1·29 = weight of 1 lit. air). But 110 c.c. of cond. gases are obtained.

0·110 × 1·7415 = 0·19 gr. of cond. gases,

thus 3·0 – 0·2 = 2·8 gr. of permanent gases.

The average mol. weight of the total gases =

$$\frac{3}{\frac{2\cdot8}{10}+\frac{0\cdot19}{40}} = 10\cdot5$$

(10 = mol. wt. of the perm. gases)
(40 = mol. wt. of the cond. gases)

*Conclusions from the Results of Experiment* 1.—From these Tables it appears that :—

1. The solid condensed product D+E+E¹ forms 93·5 per cent. of the raw material.

2. The properties of this product are approximately the same as those of the paraffin employed. This indicates that the paraffin has undergone very little cracking.

3. No liquid products are obtained.

4. The gases are formed principally of the permanent gases $H_2$ and $CH_4$ (see note, Table II.).

5. C and D+E+E¹ contain the greatest proportion of unsaturated bodies (3–5 per cent.).

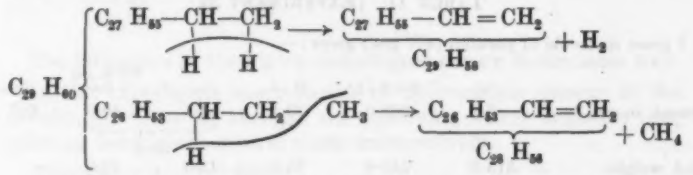
6. From the properties of C it appears that the molecule has become heavier (mol. wt. 527). It cannot be admitted that the paraffin has undergone a fractional distillation, because it was *totally* in vapour phase at the temperature and pressure realised in the experiment. The increase of the mol. weight can only be explained if it is admitted that a small quantity of a synthetic product has been formed by pyrogenic condensation.

The decomposition thus gives a heavy unsaturated hydrocarbon, which, at least partially, polymerises.

From all which it can be concluded that splitting in this experiment :—

1. Was very slight.

2. That it takes place at the extremities of the molecule, so that $H_2$ and $CH_4$ are formed as gases, whilst an unsaturated hydrocarbon remains, which partially polymerises. The reaction can thus be written as follows :—




The splitting of the molecule midway cannot be admitted, because in that case much lighter hydrocarbons would be formed. Nowhere have such lighter hydrocarbons been discovered in the products obtained.

Further, it is seen that from one molecule of hydrocarbon present in the paraffin employed on an average two molecules are obtained

*Experiment* 2.—$T_1$ : 600° C.
M : 10 mm. (max.).
Rate : 1 drop per sec.
Cracking period : 1·4 sec.

TABLE I. (EXPERIMENT 2).

*Material Employed.*

A—B = 77·5—0·5 = 77 grs.

| | *Products Obtained.* | Weight. in grs. | % | S.g. 60° 4° C. | Bromine number in w. % | Bromine number in grs. | Melt. point. | Refr. 60°. | Mol. w. |
|---|---|---|---|---|---|---|---|---|---|
| C | Solid | 1 | 1·3 | — | 3·6 | 0·036 | 55·5 | 1·4405 | 513 |
| D | ,, | 4 | 5·2 | | | | | | |
| E | ,, | 50 | 65·0 | 0·780 | 11·5 | 6·267 | 54° | 1·4359 | 449 |
| $E^1$ | ,, | 0·5 | 0·65 | | | | | | |
| F | — | — | — | — | — | — | — | — | — |
| G | Water | — | — | — | — | — | — | — | — |
| H | Liquid | 3·5 | 4·55 | — | 109 | 6·00 | — | $n\,\frac{20°}{D}$ = | 75 |
| $I_1$ | ,, | 2 | 2·6 | | | | | 1·4153 | (admitted) |
| | | | | S.G./air | | | | | |
| $I_2$ | Cond. gas 51 = 8·4 | | 10·9 | 1·305 | 290 (1) | 24·6 | — | — | 38–46 (1) |
| | Perm. gas + loss | 7·6 | 9·8 | — | 0·0 | 0·0 | — | — | 10 (admitted) |
| | | 77·0 | 100·0 | | | | | | |
| | Rangoon Paraffin | | | 0·784 | 0·0 | 0·0 | 58° | 1·4375 | 407 |

(1) Calculated from the analysis :—

| | |
|---|---|
| $CO_2$ .. .. .. .. .. .. | 12·6 per cent. |
| $C_2H_6$ and hom. .. .. .. .. | 50·0 „ |
| $C_2H_4$ .. .. .. .. .. .. | 18·8 „ |
| $C^4H^6$ .. .. .. .. .. .. | 3·0 „ |
| $O_2$ .. .. .. .. .. .. | 0·6 „ |
| CO .. .. .. .. .. .. | 4·0 „ |
| $H_2$ .. .. .. .. .. .. | 0·0 „ |
| $CH_4$ and hom. .. .. .. .. | 9·0 „ |
| | 98·0 „ |

## TABLE II. (EXPERIMENT 2).

1 gram molecule of paraffin (407 grs.) gives :—

| | C. | D+E+E¹. | H+$I_1$. | $I_2$. | Perm. gas + loss. | Total. |
|---|---|---|---|---|---|---|
| Quant. in grs. .. | 5·3 | 288·0 | 29·1 | 44·4 | 40·0 | 407 |
| | | | | 84·4 | | |
| Mol. weight .. | 513·0 | 449·0 | 75·0 | 42·0 | 10·0 | |
| | | | | 17·0 (1) | | |
| Amount of gr. mol. | 0·0103 | 0·642 | 0·388 | 1·06 | 4·0 | 6·0 |
| | | | | 5·0 | | |
| Bromine abs. by add. | 0·19 | 33·2 | 31·7 | 130·0 | 0·0 | 195·1 |
| Quant. of gr. mol. of unsaturated. | 0·0012 | 0·208 | 0·198 | 0·812 | 0·0 | 1·22 |
| Percentage of unsat. bodies. | 12% | 32% | 51% | 77% | 0% | 20% |
| | | | | 16% | | |

(1) See note, Table II. (Exp. 1).

*Conclusions from the Results of Experiment* 2.—From these tables it appears that :—

(1) The percentage of the heavy products is decreased and that of the light products increased. Thus the decomposition was much greater than in the first experiment.

(2) Liquid products are obtained.

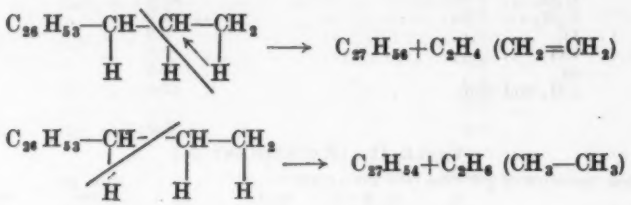
(3) The quantity of condensable gases increased in relation to that of the permanent gases. Thus there was formed smaller quantities of $H_2$ and $CH_4$ and a larger quantity of higher homologues.

(4) The proportion of unsaturated bodies is highest in the liquid products (H+$I_1$) and the condensable gases.

(5) The molecular weight of C has such a value that we must again conclude that polymerisation has taken place.

In this case too, splitting has occurred at the extremities of the molecule; principally to form light hydrocarbons, saturated and unsaturated. Thus it is only the heavy unsaturated hydrocarbons that polymerise and not the light ones.

To the formulæ given in experiment 1 we can thus add the following :—



The formation of the higher homologues occurs in the same way.

In this experiment one molecule of hydrocarbon present in the paraffin gives, on an average, six molecules, which indicates that splitting takes place several times consecutively.

*Experiment* 3.—$T_1$ : 600° C.
M : 10 mm.
Rate : 3 drops per 5 sec.
Cracking period : 1·2 sec.

Apart from the rate of introduction the conditions of this experiment were the same as the foregoing, and it will be seen that the results are approximately the same. A small decrease of decomposition is observed, which can be explained by the decrease in the time of cracking.

TABLE I. (EXPERIMENT 3).

*Material Employed.*

A—B=132—0·250=131·75 grs.

| | *Products Obtained.* | Weight. in grs. | % | S.g. 60° 4° | Bromine number in w. % | Bromine number in grs. | Melt. point. | Refr. 60°. | Mol. w |
|---|---|---|---|---|---|---|---|---|---|
| C | Solid | 0·75 | 0·6 | — | 4·0 | 0·03 | 55·6 | 1·4404 | 488 |
| D | ,, | 3·50 | 2·7 | | | | | | |
| E | ,, | 97·0 | 73·6 | 0·780 | 9·8 | 10·0 | 54·9 | 1·4363 | 438 |
| $E^1$ | ,, | 1·0 | 0·7 | | | | | | |
| F | — | — | — | — | — | — | — | — | — |
| G | Water | — | — | — | — | — | — | — | — |
| H | Liquid | 2·5 | 1·9 | | | | | $n\frac{20°}{D}$ = | |
| $I_1$ | ,, | 0·50 | 0·4 | — | 99·0 | 3·0 | — | 1·4160 | 75 (admitted) |
| | | 7 lit.= | | S.G./air | | | | | |
| $I_2$ | Cond. gas | 11·8 gr. | 8·9 | 1·31 | 240 (1) | 28·5 | — | — | 38–45(1) |
| | Perm. gas and loss | 14·7 | 11·2 | — | 0·0 | 0·0 | — | — | 10 (admitted) |
| | | 131·75 | 100·0 | | | | | | |
| | Rangoon Paraffin | | | 0·784 | 0·0 | 0·0 | 58·0 | 1·4375 | 407 |

(1) Calculated from the analysis :—

| | |
|---|---|
| $CO_2$ .. .. .. .. .. .. | 20·0 per cent. |
| $C_2H_6$ and hom. .. .. .. .. .. | 40·0 ,, |
| $C_3H_6$ .. .. .. .. .. .. | 17·0 ,, |
| $C_4H_8$ .. .. .. .. .. .. | 5·0 ,, |
| $O_2$ .. .. .. .. .. .. | 0·9 ,, |
| CO .. .. .. .. .. .. | 2·6 ,, |
| $H_2$ .. .. .. .. .. .. | 0·0 ,, |
| $CH_4$ and hom. .. .. .. .. | 12·0 ,, |
| | 97·5 ,, |

## TABLE II. (EXPERIMENT 3.)

1 gram molecule of paraffin (407 grs.) gives :—

| | C. | D+E+E¹. | H+$I_1$. | $I_2$. | Perm. gas + loss. | Total. |
|---|---|---|---|---|---|---|
| Quant. in grs. .. | 2·0 | 314·0 | 9·0 | 36·0 | 46·0 | 407 |
| | | | | 82·0 | | |
| Mol. weight .. | 488·0 | 438·0 | 75·0 | 40·0 | 10·0 | |
| | | | | 15·0 (1) | | |
| Amount of gr. mol. | 0·005 | 0·717 | 0·125 | 0·9 | 4·6 | 6·3 |
| | | | | 5·5 | | |
| Bromine abs. by add. | 0·1 | 30·8 | 9·3 | 87·0 | 0·0 | 127·0 |
| Quant. of gr. mol. of unsaturated. | 0·0006 | 0·2 | 0·06 | 0·5 | 0·0 | 0·8 |
| Percentage of unsat. bodies | 10% | 30% | 50% | 60% | 0% | 12% |
| | | | | 10% | | |

(1) See note Table II. (Exp. 1).

The conclusions to be drawn from this experiment are the same as those of experiment 2.

*Experiment* 4.—$T_1$ : 700° C.

M : 30 mm.

Rate : 1 drop per 2 sec.

Cracking period : 3·8 sec.

## TABLE I. (EXPERIMENT 4.)

*Material Employed.*

A—B=65—0=65 grs.

| | *Products Obtained.* | Weight. [in grs. | % | S.g. 60° 4° | Bromine number in w. % | Bromine number in grs. | Melt. point. | Refr. 60°. | Mol. w. |
|---|---|---|---|---|---|---|---|---|---|
| C | Solid | 0·0 | 0·0 | — | — | — | — | — | — |
| D | ,, | 0·5 | 0·8 | | | | | | |
| E | ,, | 15·0 | 23·0 | 0·780 | 34·9 | 7·5 | 49·5 | 1·4365 | 450 |
| $E^1$ | ,, | 6·0 | 9·25 | | | | | | |
| F | — | — | — | — | — | — | — | — | — |
| G | Water | — | — | — | — | — | — | — | — |
| H | Liquid | 6·0 | 9·25 | S.G. $\frac{20°}{4°}$ | 202·0 | 23·2 | — | $n_D^{20°}$ = | 75 |
| $I_1$ | ,, | 5·5 | 8·50 | =0·707 | | | | 1·4059 | (admitted) |
| | | 12 lit.= | | S.G./air | | | | | |
| $I_2$ | Cond. gas | 18·4 gr. | 28·3 | 1·18 | 383 (1) | 70·4 | — | — | 34–41 (1) |
| | Perm. gas and loss | 13·6 | 20·9 | — | 0·0 | 0·0 | — | — | 10 (admitted) |
| | | 65·0 | 100·0 | | | | | | |
| | Rangoon Paraffin | | | 0·784 | 0·0 | 0·0 | 58° | 1·4375 | 407 |

(1) Calculated from the analysis :—

| | |
|---|---|
| $CO_2$ .. .. .. .. .. .. | 6·5 per cent. |
| $C_3H_6$ and hom. .. .. .. .. | 39·5 ,, |
| $C_2H_4$ .. .. .. .. .. .. | 42·0 ,, |
| $C_6H_6$ .. .. .. .. .. .. | 1·0 ,, |
| $O_2$ .. .. .. .. .. .. | 0·2 ,, |
| CO .. .. .. .. .. .. | 0·3 ,, |
| $H_2$ .. .. .. .. .. .. | 0·0 ,, |
| $CH_4$ and hom. .. .. .. .. | 9·0 ,, |
| | 98·5 ,, |

## Table II. (Experiment 4.)

1 gram molecule of paraffin (407 grs.) gives :—

| | C. | D+E+E'. | H+I₁. | I₂. | Perm. gas + loss. | Total. |
|---|---|---|---|---|---|---|
| Quant. in grs. .. | 0 | 134·5 | 72·2 | 115·2 | 85·1 | 407·0 |
| | | | | 200·3 | | |
| Mol. weight .. | — | 450·0 | 75·0 | 37·0 | 10·0 | |
| | | | | 17·0 (1) | | |
| Amount of gr. mol. | — | 0·3 | 0·96 | 3·0 | 8·5 | 12·8 |
| | | | | 11·5 | | |
| Bromine abs. by add. | — | 46·9 | 145·8 | 441·2 | 0·0 | 633·9 |
| Quant. of gr. mol. of unsaturated. | — | 0·293 | 0·91 | 2·76 | 0·0 | 3·96 |
| Percentage of unsat. bodies. | — | 98% | 95% | 92% | 0% | 31% |
| | | | | 24% | | |

(1) See note, Table II. (Exp. 1).

*Conclusions from the Results of Experiment* 4.—The same observations as in the case of experiments 2 and 3 hold good here also, but are somewhat accentuated. The conclusions are, therefore, in the main, the same.

The decomposition has become much greater. The splitting again occurs at the extremities of the molecule, but apparently more towards the middle.

The formation of unsaturated bodies has considerably increased.

One molecule of hydrocarbon present in the paraffin gives, on an average, 13 molecules.

*Experiment* 5.—$T_1$ : 700° C.
M : 30 mm.
Rate : 1 drop per sec.
Cracking period : 1·54 sec.

Apart from the duration, this experiment is the same as foregoing.

TABLE I. (EXPERIMENT 5.)

*Material Employed.*

A—B=44—0=44 grs.

| | *Products Obtained.* | Weight. in grs. | % | S.g. 60° 4° C. | Bromine number in w. % | Bromine number in grs. | Melt. point. | Refr. 60°. | Mol. w. |
|---|---|---|---|---|---|---|---|---|---|
| C | Solid | 0·0 | 0·0 | — | — | — | — | — | — |
| D | ,, | 1·0 | 2·3 | | | | | | |
| E | ,, | 9·0 | 20·5 | 0·779 | 20·0 | 2·7 | 49·25 | 1·4364 | 454 |
| $E^1$ | ,, | 3·5 | 7·9 | | | | | | |
| F | — | — | — | — | — | — | — | — | — |
| G | Water | — | — | — | — | — | — | — | — |
| H | Liquid | 4·0 | 9·1 | S.G. 20° 4° = 0·723 | 154·5 | 10·8 | — | $n\ {}^{20°}_{D}$ = 1·4160 | 75 (admitted) |
| $I_1$ | ,, | 3·0 | 6·8 | | | | | | |
| $I_2$ | Cond. gas | 10 lit. = 15 grs. | 34·1 | S.G./air 1·16 | 400 (1) | 60·1 | — | — | 34–41 (1) |
| | Perm. gas and loss | 8·5 | 19·3 | — | — | — | — | — | 10 (admitted) |
| | | 44·0 | 100·0 | | | | | | |
| | Rangoon-Paraffin | | | 0·784 | 0·0 | 0·0 | 58·0 | 1·4375 | 407 |

(1) Calculated from the analysis :—

| | |
|---|---|
| $CO_2$ .. .. .. .. .. .. | 6·0 per cent. |
| $C_3H_6$ and hom. .. .. .. .. | 40·0 ,, |
| $C_2H_4$ .. .. .. .. .. .. | 44·2 ,, |
| $C_6H_6$ .. .. .. .. .. .. | 0·2 ,, |
| $O_2$ .. .. .. .. .. .. | 0·4 ,, |
| CO .. .. .. .. .. .. | 0·6 ,, |
| $H_2$ .. .. .. .. .. .. | 0·0 ,, |
| $CH_4$ and hom. .. .. .. .. | 6·5 ,, |
| | 97·9 ,, |

TABLE II. (EXPERIMENT 5.)

1 gram molecule of paraffin (407 grs.) gives :—

| | C. | D+E+E'. | H+$I_1$. | $I_2$ | Perm gas + loss. | Total. |
|---|---|---|---|---|---|---|
| Quant. in grs. .. | 0 | 124·9 | 64·7 | 138·8 | 78·6 | 407·0 |
| | | | | 21·4 | | |
| Mol. weight .. | — | 454·0 | 75·0 | 37·0 | 10·0 | |
| | | | | 18·0 (1) | | |
| Amount of gr. mol. | — | 0·27 | 0·86 | 3·75 | 7·86 | 12·74 |
| | | | | 11·61 | | |
| Bromine abs. by add. | — | 25·0 | 100·0 | 555·2 | 0·0 | 680·2 |
| Quant. of gr. mol. of unsaturated. | — | 0·156 | 0·625 | 3·47 | 0·0 | 4·251 |
| Percentage of unsat. bodies. | — | 57·8% | 72·6% | 92·5% | 0 | 33% |
| | | | | 29·7% | | |

(1) See note, Table II. (Experiment 1).

The conclusions from experiment 5 are the same as those for the previous experiment.

*Graphs.*—If the above results are expressed in the form of graphs, the conclusions to be drawn become more apparent, and it is more easy to arrive at a generalisation.

Figure 3 gives the percentages of the different products obtained in relation to the temperature, and it is at once seen that the percentage of solid condensed products decreases, and that of the liquid and

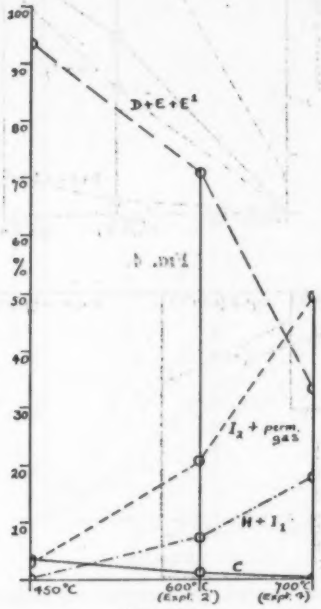



FIG. 3.

gaseous products increases, so that the splitting becomes more important with increase of temperature as regards the lighter products.

Figure 4 gives the bromine value in percentage of weight of the different products in relation to the temperature. From this it is seen that the proportion of unsaturated bodies increases, chiefly in the gas and liquid products.

In figure 5 the vertical axis gives the quantity in grams of the different products obtained from 100 grams of paraffin, and the horizontal axis the bromine value (in weight%) of the same product.

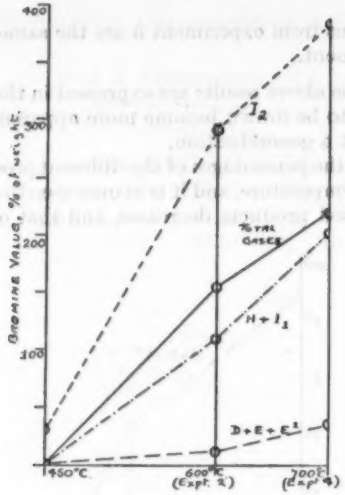

400
300
200
100
BROMINE VALUE, % of weight
$I_2$
TOTAL GASES
$H+I_1$
$D+E+E^1$
450°C.
600°C. (Expt. 2)
700°C. (Expt. 4)

FIG. 4.

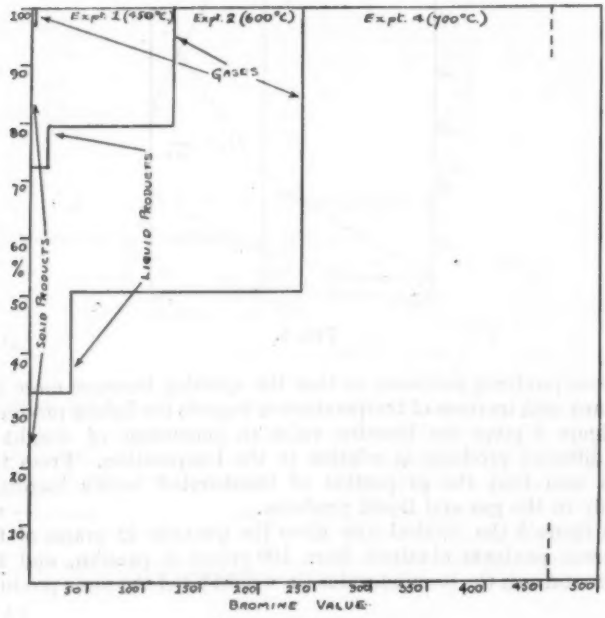

Expt. 1 (450°C.)
Expt. 2 (600°C.)
Expt. 4 (700°C.)
GASES
LIQUID PRODUCTS
SOLID PRODUCTS
% BY WEIGHT
100
90
80
70
60
50
40
30
20
10
300
1001
1501
2001
2501
3001
3501
4001
4501
5001
BROMINE VALUE

FIG. 5.

Thus a graph is obtained which gives a good idea of the extent of the decomposition, and it is seen that this is very small at 450° C., but increases successively and very rapidly with the temperature.

Figure 6 gives the quantity of unsaturated molecules per 100 molecules of the product obtained (taken from the different tables 2) in relation to the temperature. It shows that molecules

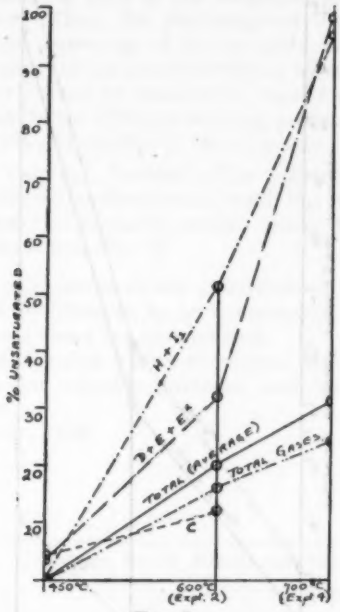



FIG. 6.

of unsaturated bodies are increasingly formed, and that at 700° C. the proportion of unsaturated products in the liquid and solid portions approaches 100 per cent.

Figure 7 gives the number of molecules of the different products obtained from one molecule of paraffin for the various temperatures. This also shows that decomposition becomes greater with an increase of temperature and that the increase of decomposition is accompanied by an increase in the proportion of light products.

## GENERAL CONCLUSIONS AND SUMMARY.

*The Splitting.*—At 450° C. the splitting is much greater in vapour phase than in liquid phase, which can be explained by the greater

mobility and consequent activity of the gaseous molecule, and also by the relatively greater influence of the hot wall of the iron tube and the surface of the filling material.

At high temperature the splitting is very much greater.

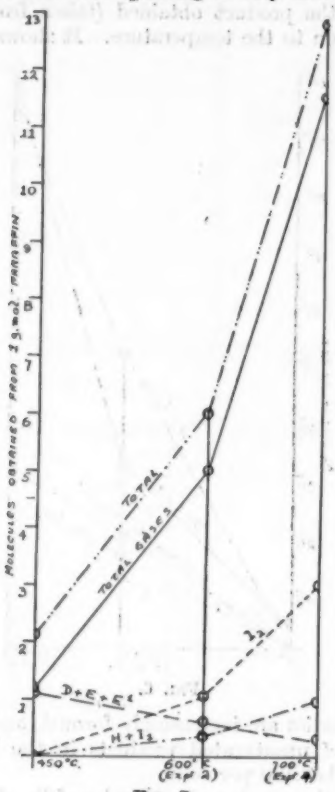



FIG. 7.

*The Place of the Splitting.*—At and above 450° C. in vapour phase the splitting undoubtedly takes place at the extremities of the molecules. This result is in accordance with what has been found in previous experiments, in which the cracking took place in liquid phase.

It was, in fact, shown that $H_2$ splits off at as low a temperature as 360°.[6]

[6] Waterman, Perquin & Van Westen. *J. Inst. Petr. Techn.*, 1930, 16, 29.

Further, from the graphs given by Perquin[7] it is seen that the maximum percentage of different fractions obtained moves from the heavier products towards the lighter products as the cracking period becomes longer. This can easily be explained if the splitting occurs at the extremities of the hydrocarbon molecules present in the paraffin. This splitting, which occurs in successive steps for the remaining part of the molecule, makes this latter lighter and lighter. Thus, the percentage of the light products increases whilst the percentage of heavy products decreases.

From the agreement of the results obtained by cracking in liquid phase with those obtained by cracking in vapour phase it appears that most probably, in the different cracking processes, the splitting always begins at the extremities of the molecule.

*Nature of the Cracking Products.*—The splitting is such that principally unsaturated hydrocarbons (with $H_2$) are formed. At 700° C. the non-gaseous products contain nearly 100 per cent. of unsaturated products (see Fig. 6).

The splitting which occurs at the extremities of the molecule is thus accompanied, or followed, by an expulsion of $H_2$, so that the total hydrocarbons formed are unsaturated.

In conclusion, the writer wishes to express his thanks to Prof. H. I. Waterman for valuable guidance and for permission to publish this paper.

DELFT, December, 1929.

[7] J.N.J. Perquin. "Bijdrage tot de Kennis van het Bergius-Orsees." *Thesis, Delft*, 1929.

# The Cause of Gummy Pistons.*

By G. D. Boerlage.

The phenomenon of gummy pistons is well known and has hitherto been believed to be caused either by bad fuel or by a bad lubricant, but careful investigations of the particular case described below have shown that neither the fuel nor the lubricant were responsible. On the strength of these experiments it can now be stated that only in exceptional cases is the trouble caused by bad fuel or lubricant. As a rule bad combustion is to blame.

The phenomenon was first investigated with a small, medium pressure, hot bulb, 7-h.p. engine which, when idling, appeared to be extremely sensitive to differences in fuel.

After running the engine for one hour without load, apparently with no trouble, it was stopped and left alone for half an hour. It then proved to be impossible to restart the engine; the fly-wheel could not be turned and the piston was stuck. After dismantling the engine it appeared that both piston and cylinder were covered with a gummy substance, very much like dry varnish. The running surface had a shiny, dark brown to black colour and the gummy substance could not be removed by rubbing or scratching with the fingers, but only by using hot benzole or emery-cloth.

It might be thought that the combustion was so bad as to give a dark exhaust and appreciable incrustation in the combustion chamber, but on the contrary the exhaust was rather clean, only occasionally bluish by misfiring, and there was practically no incrustation at all. Incrustation certainly was not the cause of the trouble.

Figs. 1 and 2 show the clean and blackened piston.

Figs. 3 and 4 show the clean and blackened cylinder.

A series of tests[1] with different fuels and widely varying lubricants proved that neither the fuel nor the lubricant were the cause, but that the phenomenon had to be attributed to engine and fuel not harmonizing under certain conditions. Many tests were made,

* Paper received July 5th, 1930.

[1] In the Engine Testing Laboratory Proefstation "Delft," Holland, by Ir. J. J. Broeze and B. J. J. Gravesteyn.

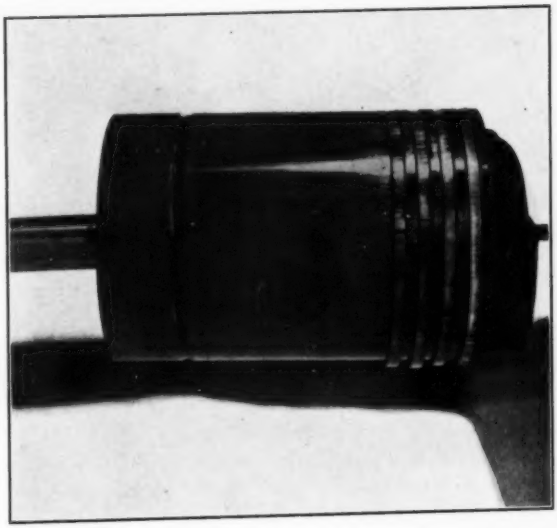


FIG. 1.

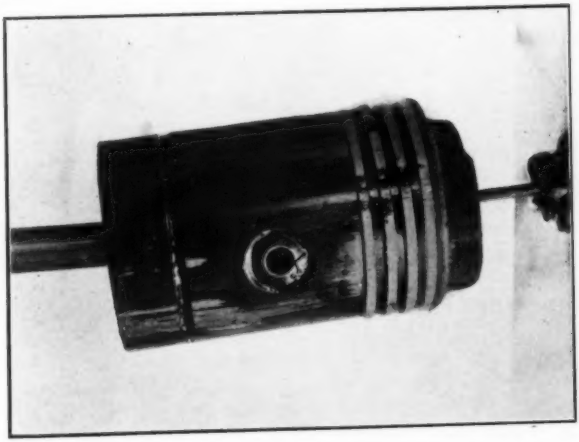


FIG. 2.

FIG. 4.

FIG. 3.

with different fuels and the following figures are typical for the respective fuels used and their behaviour in the engine:

| | Kerosine A | Gas Oil B | Gas Oil C | Gas Oil D |
|---|---|---|---|---|
| Initial Boiling Point ° C. .. | 157 | 200 | 220 | 217 |
| 50% Distillation Temperature | 219 | 264 | 267 | 309 |
| Formation of carbon (Conradson) | 0 | 0·04 | 0·12 | 0·30 |
| Viscosity (Engler) .. .. | 1·09 | 1·29 | 1·44 | 1·59 |
| Behaviour in the engine in question .. .. .. | Bad | Good | Fair | Very Good |

Normal motor cylinder oils, edeleanised oils and even rape-seed oil were used as lubricants.

The engine was run for 2½ hours at a time without load, each time on various combinations of fuel and lubricating oil. By means of the lamp, or in some other way, the ignition was so adjusted that in the one series of tests the ingition, and consequently the combustion, took place *normally*, whereas in the other series of tests, ignition and combustion were purposely *abnormal*.

The result was surprising. The forming of the varnish took place very regularly and very distinctly when the ignition faltered and practically to the same extent, independent of the grade of fuel and of the grade of lubricating oil used. The only exception found was when rape-seed oil was used, in which case the varnish was more sticky and it took about half a day before the varnish became quite hard.

Evidently the *quality* of the fuel and of the lubricating oil are immaterial with regard to the phenomenon in question.

From the above-mentioned figures one would expect that gas oil D would be the worst. As a matter of fact, gas oil B was found to be the best for *normal* engines, but curiously enough, gas oil D was the most suitable for an *abnormally running* engine.

The test is pre-eminently suitable for demonstration, considering that within one hour the phenomenon can be demonstrated, whereas with normal combustion, even when using the most inferior grades of oil, the piston and the cylinder remain practically clean, showing hardly any difference, yet a difference could be expected in view of the variations in the Conradson figures.

Further investigation showed that this phenomenon was by no means restricted to the small hot bulb engine, but that it occurred with all kinds of oil engines. To prove this, it was sufficient to arrange purposely in one way or another a faltering ignition and a faulty combustion, as above referred to. It goes without saying that in certain engines (hot bulb) this could be done without much difficulty, whereas in high-pressure engines it could not be done without artificial manipulations.

In cases like the one discussed above it should be frankly admitted that the fault lies with the ignition and combustion in the engine. The cause of the evil being proved, it is better to solve the problem in this way than by searching for fuels of unusual specifications in the hope that some compound might be capable of masking the fault of the engine.

These tests were arranged so as to show the phenomenon as distinctly as possible, and it is conceivable that in most cases similar troubles will be less clear. It is possible that the same cause might have given trouble in many cases where the fault was imputed, for instance, to observed incrustations, although these incrustations might have been comparatively harmless.

The outcome of the foregoing tests clearly shows that this phenomenon should be generally known, as it gives an explanation of, and at the same time gives means for overcoming difficulties experienced with oils in internal combustion engines, which difficulties should be attributed to bad combustion rather than to the quality of fuel and lubricant.

# An Examination of Clays associated with Oil-bearing Strata in the United States.*

By E. McKenzie Taylor, M.B.E., Ph.D., D.Sc., F.I.C.
School of Agriculture, Cambridge.

## Introduction.

In a previous communication (1) it was suggested that petroleum has been formed as the result of the decomposition by bacteria of organic matter (probably fats and proteins) under the alkaline anærobic conditions imposed by a layer of sodium clay undergoing hydrolysis in fresh water. The suggestion was supported by the results of an examination of a series of cap-rocks from the oilfields in Rumania and the West Indies. Further evidence in favour of this hypothesis was obtained in the examination of cap-rocks from Trinidad, Mexico and Alsace (2). The cap-rocks were shown to contain sodium clay formed as the result of base exchange with solutions of sodium salts, and the sodium clay was shown to be alkaline, indicating that it had been in contact with fresh water since its formation. Since the publication of the two papers referred to above, shales from oil-bearing strata in the United States have been obtained and examined. The results of this examination are recorded in this paper.

## Origin and Description of Specimens.

The details of the origin, geological formation, and the depth from which the specimens were obtained are as follows :

(1) Gypsy Oil Company, Hughes County, Okla. Shale of basal Pottsville age, basal Pennsylvanian, topping "Cromwell" sandstone of basal Pottsville age ; unconformity on top of sand, gas found at 3300 feet.

(2) Gypsy Oil Company, Lincoln County, Okla. Shale of upper Cherokee age, lower Allegheny, Pennsylvanian, topping "Prue" sandstone of the same age. Top of sand at 3303 feet, oil encountered at 3320 feet.

(3) Gypsy Oil Company, Tulsa County, Okla. Shale of upper Pottsville age, lower Pennsylvanian, topping "Dutcher" sandstone of the same age. Gas at 1565 feet.

(4) Gypsy Oil Company, same location as (3). Black Chattanooga shale of basal Mississippian age, resting unconformable on arenaceous dolomite and dolomitic sand of the upper Simpson formation, Ordovician. Oil at 2048 feet.

(5) Gypsy Oil Company—Marland Oil Company, Osage County, Okla. Green shale of upper Simpson age, Ordovician, resting on "Wilcox" sandstone of the same age. The shale bed measures 5 feet in thickness. Top of sand at 2854 feet, oil at 2861 feet.

(6) Marland Oil Company, Grant County, Okla. Black Chattanooga shale of basal Mississippian age resting unconformable on "Wilcox" sandstone of upper Simpson age, Ordovician. Oil at 4339 feet.

(7) Amerada Petroleum Corporation, Christian Well, Smith County, Texas. Shale overlying Woodbine sand. Depth 5317 feet.

* Paper received July 9th, 1930.

(8) Amerada Petroleum Corporation, Christian Well, Smith County, Texas. Overlying upper Woodbine sand. Depth 5112 feet.

(9) Atlantic Oil Producing Company, Navarro County, Texas. Powell Field, Eagleford Shale, Benton Age, at Dakota contact. Depth 2857 feet.

(10) Atlantic Oil Producing Company, Navarro County, Texas. Currie Field, Eagleford Shale, Benton age, immediately above Dakota Sand. Depth 2985 feet.

(11) Western Gulf Oil Company, Fruitvale Oil Field, Kern County, California. Depth 2590 feet, overlies barren sand at 2600 feet.

(12) Same as (11). Depth 3612 feet, overlies barren sand at 3615 feet.

(13) Same as (11). Depth 3613 feet, overlies barren sand at 3615 feet.

(14) same as (11). Depth 3595 feet. Overlies rich oil sand at 3600 feet.

(15) Same as (11). Depth 3597 feet. Overlies rich oil sand at 3600 feet.

(16) Same as (11). Depth 3598 feet. Overlies rich oil sand at 3600 feet.

(17) Gulf Refining Company of Louisiana, Caddo Parish, La. Shale of Tokio age. Depth 2393 feet. Oil at 2395–2398 feet.

(18) Standard Oil Company of California. Shale from "North Dome." Kettleman Anticline, Coalinga district. Sample from base of the diatomaceous brown shale, either middle Miocene or upper Miocene in age. Depth 6386 feet. Sample taken just above first oil sand, Well 41.

(19) Same as (18) Well 81. Depth 6080 feet. Sample taken 2 feet above first sand.

## Methods of Examination.

The methods used in the examination of the specimens have already been described (3). The pH value of each specimen was determined. The replaceable sodium and calcium were estimated by replacement with normal ammonium acetate solution and expressed as milligram equivalents per 100 grams shale. The results obtained are shown in Table I.

Table I.

| Spec. No. | pH Value. | Replaceable Bases (milligram equivalents per 100 grams shale). Na | Ca |
|---|---|---|---|
| 1 | 9·4 | 12·4 | 5·6 |
| 2 | 9·2 | 7·2 | 0·8 |
| 3 | 8·6 | Insufficient for determination. | |
| 4 | 8·6 | 5·7 | 4·0 |
| 5 | 9·0 | 7·7 | 4·2 |
| 6 | 8·4 | Insufficient for determination. | |
| 7 | 10·4 | 21·0 | 5·0 |
| 8 | 8·6 | 16·8 | 2·3 |
| 9 | 9·0 | 19·0 | 6·6 |
| 10 | 9·0 | 13·8 | 6·5 |
| 11 | 9·6 | 11·2 | 4·1 |
| 12 | 8·6 | 6·3 | 4·2 |
| 13 | 8·4 | 6·3 | 4·4 |
| 14 | 8·8 | 8·7 | 1·8 |
| 15 | 8·8 | 7·3 | 3·4 |
| 16 | 9·0 | 5·8 | 2·2 |
| 17 | 9·2 | 17·6 | 6·6 |
| 18 | 9·6 | 27·7 | 9·9 |
| 19 | 9·8 | 29·6 | 7·1 |

## Discussion of Results.

From Table I. it will be seen that all the specimens are alkaline. Further, the amount of replaceable sodium present is greatly in excess of the amount of replaceable calcium. These results show, therefore, that base exchange between the clays and solutions of sodium salts has taken place and that the clay has subsequently been in contact with fresh water leading to the hydrolysis of the sodium clay and the production of alkalinity. As the result of the production of alkalinity, the clay is deflocculated and, therefore, impermeable. The shales provide the alkaline anærobic conditions which have been postulated. These results are in complete agreement, therefore, with those previously recorded in connection with the examination of the shales associated with oil-bearing strata of other countries.

A further point of interest is that the shales examined for this communication range in age from Ordovician to upper Miocene. *It appears, therefore, that the shales associated with oil-bearing strata, irrespective of geological age or country of origin, are all alkaline and contain sodium clay as the characteristic clay constituent.* This conclusion indicates that all the shales associated with oil-bearing strata have been formed under a constant set of conditions, *i.e.*, conditions under which base exchange between clay and solutions of sodium salts could take place and the sodium clay thus formed be subsequently subjected to hydrolysis in fresh water. No exception to this rule has been found in the shales so far examined.

## Acknowledgments.

The Author is indebted to the Director of the Geological Survey of the United States for suggesting the names of geologists willing to supply specimens, and in particular indebted to the following gentlemen for the trouble they have taken to supply the specimens which form the subject of this paper:—Mr. Sidney Powers, Tulsa, Okla.; Mr. George C. Gester, San Fransico; Mr. William E. Wrather, Dallas, Texas; Mr. Hoyt S. Gale, Los Angeles, and Mr. W. B. Wilson, Tulsa, Okla.

## References.

(1) E. McK. Taylor, "The Bearing of Base Exchange on the Genesis of Petroleum." *J. Inst. Petr. Techn.*, 1928, **14**, 839.

(2) E. McK. Taylor, "The Replaceable Bases in the Clays and Shales overlying Petroliferous Strata." *J. Inst. Petr. Techn.*, 1929, **15**, 207–210.

(3) E. McK. Taylor, *loc. cit.* p. 831.

# The Determination of the Gum Content of Cracked Spirits.*

By W. Littlejohn (Associate Member), W. H. Thomas, A.R.S.M. (Associate Member), and H. B. Thompson, Ph.D. (Member).

Hitherto the usual method of carrying out determinations of gum present in cracked spirit has been to evaporate 25 c.c. of the sample from a glass dish placed on a steam bath. When all the spirit had evaporated, the dish with its content of gum was dried in the steam oven for a certain time (say one hour), cooled in a desiccator, and finally weighed. This method however is open to certain serious objections. Firstly, it is possible on occasions to obtain discordant results. Secondly, the gum content of a petrol blend containing cracked spirit when determined by this method is very rarely the arithmetic mean of the gum contents of the constituents of the blend.

Attention was therefore concentrated on so adjusting or altering the method of test as to give concordant results and to find out the reason for the second objection given above.

It appeared from the preliminary experiments that much depended on the control of the evaporation on the steam bath and on the subsequent drying of the gummy material. Accordingly, numerous series of experiments were carried out in order to determine the effect of variables such as conditions and time of evaporation, quantity evaporated, and time and temperature of drying of the gum.

*The Influence of Air Currents during Steam Bath Evaporation.*—In view of the anomalous results which have obtained on occasions in the past when using a steam bath installed in the open laboratory, it was decided to set up a steam bath in a room as free from draughts as possible. The bath was 24 in. long by 12 in. wide by 4½ in. deep, and was provided with two rows of 7 holes (2 in. diameter) and a vertical copper draught screen 12 in. high running down the centre of the bath between the two rows of holes. It was heated by live steam introduced through a perforated pipe lying along the bottom of the bath, and a reflux condenser was provided to prevent any considerable escape of steam into the room. It was thought that this method of heating would cause less draught round the bath than would heating by gas flame and would also

* Paper received September 10, 1930.

minimise fire risk. A later improvement consists in boiling the water of the bath by means of an electrical resistance element.

For reference purposes the holes were numbered 1–14, commencing at the front left-hand corner and going round the bath in a clockwise direction.

In order to try out the bath, a spirit was used which gave results varying from 41 to 57 milligrams per 100 c.c. on the unsheltered steam bath. The results obtained are given below :—

TABLE I.

| Hole No. | | 1 | 4 | 7 | 9 | 11 | 13 |
|---|---|---|---|---|---|---|---|
| Gum .. | { | 40 | 46 | 47 | 62 | — | 82 |
| | { | 32 | — | 44 | 68 | 69 | 74 |

These results were considerably more irregular than any previously obtained, and therefore it was determined to try the effect of a jet of air at constant pressure playing on the surface of the spirit in each dish.

To this end two brass headers were made, $\frac{5}{8}$ in. internal diameter, adjustable for height and running horizontally over each row of holes. Over the centre of each hole was a jet from the header and each jet was closed with $\frac{1}{16}$ in. thick brass plate through which was bored a hole 0·036 in. in diameter. The headers were connected at one end to a manometer and at the other to an air supply whose pressure could be varied.

A set of determinations was carried out on each of three different spirits, the air jets being $1\frac{1}{2}$ in. above the top of the bath and the pressure of the air supply being equivalent to $\frac{1}{2}$ in. of water.

Results obtained are tabulated below :—

TABLE II.

| Hole No. | 1 | 4 | 7 | 8 | 11 | 14 | Steam bath with no air jet. |
|---|---|---|---|---|---|---|---|
| Spirit A .. | 6 | 7 | 6 | 6 | 6 | 6 | 11 |
| „ B .. | 38 | 37 | 36 | 36 | 37 | 35 | 50 |
| „ C .. | 263 | 265 | 265 | 262 | 262 | 263 | 308 |

In all cases the dishes were left on the steam bath for one hour and dried for one hour in the steam oven.

These results appeared so promising that experiments were carried out under varying conditions to see whether these were critical. The effect of varying the height of the air jet above the spirit surface was first tried at constant air pressure.

The header was inclined "fore and aft" from the horizontal, so that the jet was 1 in. above the top of the bath at hole 8, $1\frac{1}{2}$ in. above hole 10, $1\frac{3}{4}$ in. above hole 12 and 2 in. above hole 14.

The height of the jet appeared to have little influence within these limits, as is shown by the following results :—

TABLE III.

| Hole No. | 8 | 10 | 12 | 14 |
|---|---|---|---|---|
| Gum .. | 38 .. | 37 .. | 37 .. | 40 |

The effect of varying the amount of air passing through the jets was then determined, the jets being 1½ in. above bath level.

TABLE IV.

| Hole No. | 8 | 11 | 14 | Time of evaporation. |
|---|---|---|---|---|
| Air pressure 0·25 in. | 63 .. | 70 .. | 70 .. | 1½ hours |
| „ „ 0·5 in. | 46 .. | 47 .. | 45 .. | 1 hour |
| „ „ 0·75 in. | 57 .. | 56 .. | 54 .. | ¾ hour |

The above results appear to indicate that the air pressure has a profound bearing on the results, and that both increased time of evaporation and increased supply of air, although accompanied in the latter case by decreased time of evaporation, bring about increased gum formation.

In order to obtain decreased time of evaporation, metallic dishes were employed instead of glass. These were made of thin aluminium and of thin copper, and were of the same shape and dimensions as the standard glass dishes, the surfaces being buffed.

Air pressure was 0·5 in. and jets 1½ in. above bath level.

TABLE V.

| | Hole No. | Duration. | Gum. |
|---|---|---|---|
| Glass .. .. | 13 .. | 55 minutes .. | 53 |
| Copper .. .. | 9 .. | 45 „ .. | 86 |
| Aluminium .. | 11 .. | 40 „ .. | 71 |

Apart from the possibilities of catalysis by the metals, these results appear to indicate that the high temperature of the spirit during evaporation due to high conductivity of the metal outweighs the shorter time of evaporation. It was found that the use of an inert gas instead of air did not give any lower results.

From the figures recorded above, it will be seen that by using the controlled air jet to overcome adventitious draughts during evaporation, it is at least possible to obtain concordant results which have not hitherto been readily obtainable.

*The Influence of Quantity of Gum and Conditions of Drying on the Gum Determination.*—In the first series of experiments, vacuum evaporation was compared with steam bath evaporation, the gums

obtained being dried in the steam oven for varying degrees of time. The quantity of spirit taken in the former case was 50 c.c., and in the latter 25 c.c. Vacuum evaporation was carried out from tared 100 c.c. round-bottom flasks fitted with a modified Perkin triangle, the vacuum being obtained by means of an efficient rotary vacuum pump. The flask containing the spirit was immersed in an actively boiling water bath and vacuum was increased as fast as possible without causing ebullition of the charge, the total time of evaporation being half an hour. The flask, at the end of this time, was placed in the steam oven for the requisite period and finally weighed. The steam bath used for evaporation of spirits in glass dishes

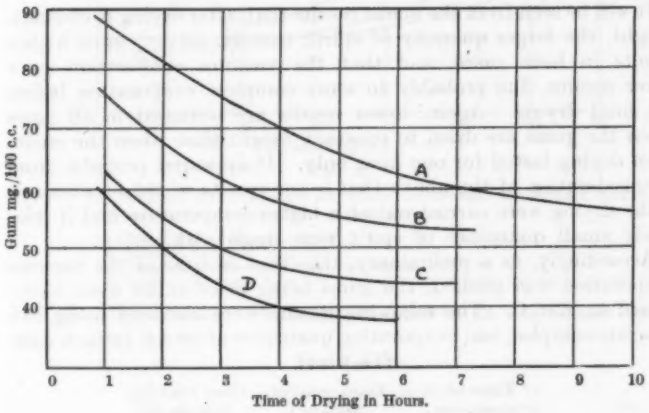



FIG. 1.

EFFECT OF TIME OF DRYING OF GUMS OBTAINED BY STEAM BATH AND VACUUM EVAPORATION.

A. Steam Bath, 50 c.c. charge.
B. Vacuum, 50 c.c. charge.
C. Steam Bath, 25 c.c. charge.
D. Vacuum, 25 c.c. charge.

was that described in the first part of this paper. It was found that with both methods of evaporation, reasonably concordant results could be obtained provided that drying of the gum was identical in each case.

The following are the results in milligrams per 100 c.c. of the first series of experiments using the same sample of spirit throughout (shown graphically in Fig. 1).

TABLE VI.

*Gum Contents.*

| Time of drying hours. | Vacuum evaporation of 25 c.c. | Steam bath test 25 c.c. charge. | Vacuum evaporation of 50 c.c. | Steam bath test 50 c.c. charge. |
|---|---|---|---|---|
| 1 | 59 | 63 | 76 | 90 |
| 2 | 50 | 55 | 68 | 81 |
| 3 | 44 | 50 | 62 | 75 |
| 4 | 40 | 47 | 58 | 70 |
| 5 | 38 | 45 | 55 | 66 |
| 6 | 38 | 44 | 54 | 63 |
| 7 | — | 44 | 53 | 60 |
| 8 | — | — | — | 59 |
| 9 | — | — | — | 57 |
| 10 | — | — | — | 56 |

It will be seen from the above results that, after drying to constant weight, the larger quantity of spirit, namely, 50 c.c., gave higher results in both cases, and that the vacuum evaporation gave lower results, due probably to more complete evaporation before the final drying. Again, lower results are obtained in all cases when the gums are dried to constant weight than when the steam oven drying lasted for one hour only. It appeared probable from a consideration of the above that lower results would be obtained if the drying were carried out at a higher temperature and if relatively small quantities of spirit were dealt with.

Accordingly, as a preliminary, the effect of time of the vacuum evaporation was studied, the gums being dried in an oven maintained at 130° C. The following results were obtained using two separate samples, and evaporating quantities of 40 c.c. in each case.

TABLE VII.

| Time of evaporation. | Gum content. Sample I. | Gum content. Sample II. |
|---|---|---|
| ½ hour | — | 34 |
| ¾ „ | 23 | 31 |
| ¾ „ | — | 33 |
| 1 „ | 34 | 39 |
| 2 hours | 45 | — |
| 3 „ | 57 | — |

It will be seen that the longer the time occupied for evaporation, the larger was the gum content, due very possibly to polymerisation by heat. Provided that the time of evaporation does not exceed half to three-quarters of an hour, the gum does not appear to increase to any considerable extent. In subsequent work, therefore, all vacuum evaporations were timed to take half an hour.

Having decided the time of evaporation, the next section of this work dealt with the comparison of vacuum and steam bath evaporation using varied quantities of spirit , and in the case of the former

an added feature in the form of drying in an atmosphere of nitrogen was introduced. The gums were dried to constant weight at

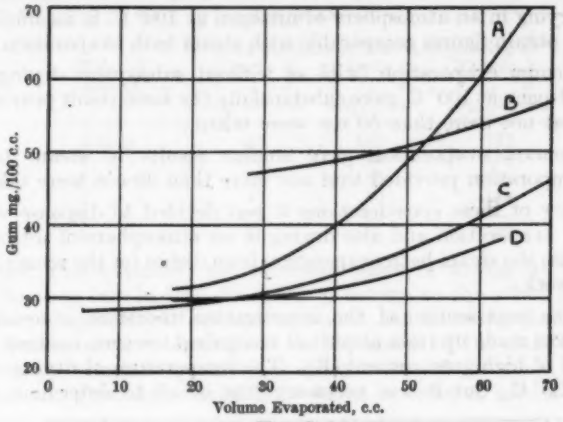



FIG. 2.

EFFECT OF VOLUME EVAPORATED ON GUMS OBTAINED BY STEAM BATH AND VACUUM EVAPORATION.

A. Steam Bath, drying at 130° C.
B. Vacuum, drying in $N_2$ at 100° C.
C. Vacuum, transferred to dishes and drying at 130° C.
D. Vacuum, drying in $N_2$ at 100° C., transferred to dishes and drying at 130° C.

130° C. The results obtained are shown in the Table below and in Fig. 2 :—

TABLE VIII.

| Volume evaporated. | Gum contents determined by (a) Steam bath evaporation in dishes, drying to constant weight @ 130° C. | (b) Vacuum evaporation, gums transferred to dishes and dried to constant weight @ 130° C. | (c) Vacuum evaporation and drying in $N_2$ @ 100° C. | (d) Vacuum evaporation, drying in $N_2$ @100° C., gums transferred to dishes and dried to constant weight @ 130° C. |
|---|---|---|---|---|
| | mg/100 c.c. | mg/100 c.c. | mg/100 c.c. | mg/100 c.c. |
| 5 c.c. | — | 28 | — | — |
| 10 „ | — | 28 | — | — |
| 15 „ | — | 29 | — | — |
| 20 „ | 34 | 28 | 31 | 29 |
| 30 „ | 31 | 31 | 47 | 32 |
| 40 „ | 43 | 34 | 49 | 33 |
| 50 „ | 48 | 36 | 51 | 34 |
| 60 „ | 70 | 42 | 55 | 36 |
| 70 „ | 69 | 46 | 55 | — |

From the foregoing results and from the diagram it will be seen that:—

(*a*) Drying in an atmosphere of nitrogen at 100° C. is insufficient to obtain figures comparable with steam bath evaporation;

(*b*) vacuum evaporation (with or without subsequent drying in nitrogen at 100° C. gave substantially the same result provided that not more than 50 c.c. were taken;

(*c*) vacuum evaporation gave similar results to steam bath evaporation provided that not more than 30 c.c. were taken.

In view of these considerations it was decided to dispense with vacuum evaporation and also drying in an atmosphere of nitrogen and to use the steam bath evaporation from dishes for the remainder of the work.

For the next section of the investigation, therefore, a series of blends was made up from a spirit of recognised low gum content (A) and one of high gum content (B). The temperature of drying was again 130° C., but it was necessary first of all to determine the

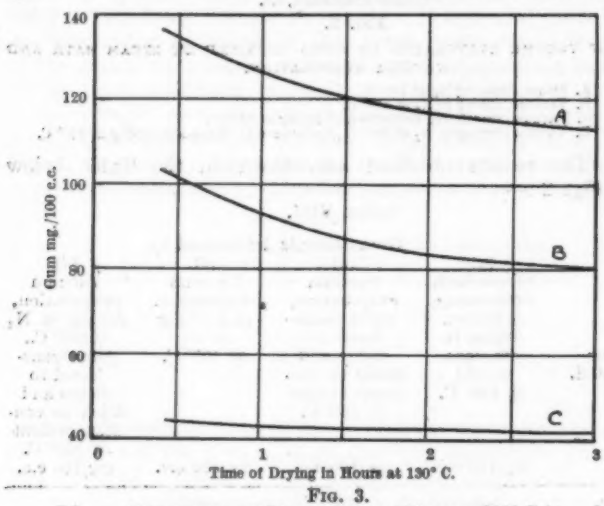



FIG. 3.

EFFECT OF TIME OF DRYING GUMS AT 130° C.

A. Weight of Gum 0·03 gms.
B. ,, ,, 0·02 ,,
C. ,, ,, 0·01 ,,

minimum amount of time required to attain constant weight. Accordingly, six quantities of 25 c.c. of each of three of the blends mentioned above were evaporated from dishes on the steam bath

and the gums obtained dried for varying degrees of time, with the following results (Fig. 3):—

TABLE IX.

| Time of drying. | Gum contents of blends, consisting of 7 parts A. 3 „ B. mg/100 c.c. | 5 parts A. 5 „ B. mg/100 c.c. | 3 parts A. 7 „ B. mg/100 c.c. |
|---|---|---|---|
| ½ hour | 44 | 101 | 137 |
| 1 „ | 43 | 92 | 126 |
| 1½ hours | 42 | 88 | 121 |
| 2 „ | 41 | 80 | 111 |
| 2½ „ | 41 | 83 | — |
| 3 „ | 41 | — | 113 |

From this evidence, the minimum time of drying at 130° C. was fixed at two hours. In order to determine the effect on gum content of quantity of spirit evaporated, the following three series of experiments were carried out on the blends of (A) and (B). In the first, a constant quantity of spirit was used (25 c.c.); in the second the quantity of spirit was varied in order to give a weight

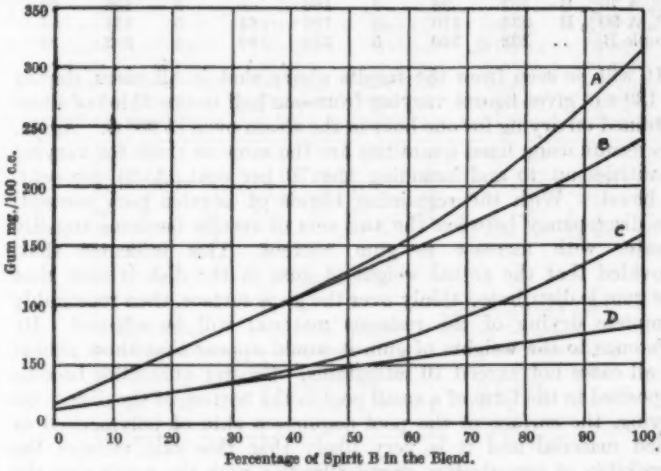



FIG. 4.

EFFECT OF VARYING QUANTITY OF SPIRIT ON GUM CONTENT.

A. 25 c.c. of spirit, gum dried for one hour at 100° C.
B. Varied quantities of spirit, gum dried for one hours at 90° C.
C. 25 c.c. of spirit, gum, dried for two hours at 130° C.
D. Varied quantities of spirit, gum dried for two hours at 130° C.

of dried gum not exceeding 10 milligrams; while in the third the same varied quantities were used, the volumes being made up to 25 c.c. with gum-free light benzine. In all cases, for the purpose

of comparison with the existing gum test, parallel experiments were carried out with drying of the gum for one hour in the steam oven.

The results obtained are shown in the table below and also in Fig. 4:—

TABLE X.

| Blend. | Fixed quantities (25 c.c.). Drying for 1 hr. @ 90° C. | Fixed quantities (25 c.c.). Drying for 2 hrs. @ 130° C. | Varying quantities. Quantity c.c. | Varying quantities. Drying for 1 hr. @ 90° C. | Varying quantities. Drying for 2 hrs. @ 130° C. | Varying quantities made up to 25 c.c. with gum-free spirit. Quantity c.c. | Varying quantities made up to 25 c.c. with gum-free spirit. Drying for 1 hr. @ 90° C. | Varying quantities made up to 25 c.c. with gum-free spirit. Drying for 2 hrs. @ 130° C. |
|---|---|---|---|---|---|---|---|---|
| Sample A .. | 17 | 12 | 25 | 17 | 12 | 25 | 17 | 12 |
| 90% A 10% B | 41 | 20 | 25 | 41 | 20 | 25 | 41 | 20 |
| 80% A 20% B | 64 | 28 | 15 | 65 | 29 | 15 | 57 | 23 |
| 70% A 30% B | 89 | 40 | 15 | 92 | 39 | 15 | 75 | 30 |
| 60% A 40% B | 110 | 48 | 10 | 109 | 44 | 10 | 89 | 39 |
| 50% A 50% B | 139 | 63 | 10 | 132 | 51 | 10 | 107 | 47 |
| 40% A 60% B | 148 | 83 | 10 | 145 | 60 | 10 | 126 | 53 |
| 30% A 70% B | 192 | 98 | 5 | 166 | — | 5 | 136 | 60 |
| 20% A 80% B | 223 | 110 | 5 | 196 | 64 | 5 | 154 | 68 |
| Sample B .. | 322 | 160 | 5 | 224 | 80 | 5 | 202 | 82 |

It will be seen from the results above that in all cases, drying at 130 c.c. gives figures varying from one half to one third of those obtained on drying for one hour in the steam oven at 90° C. Again, the results using fixed quantities are the same as those for varying quantities up to and including the 70 per cent. A–30 per cent. B blend. With the remaining blends of heavier gum content, the discrepancy between the two sets of results becomes steadily greater with increase in gum content. This indicates that, provided that the actual weight of gum in the dish is such that the gum is distributed thinly over the glass surface, then reasonably complete drying of the resinous material will be effected. By reference to the weights of gum it would appear that these should in all cases not exceed 10 milligrams. Greater quantities become deposited in the form of a small pool in the bottom of the dish. On drying, the surface of the pool acquires a skin of polymerised or dried material and it is very likely that this skin reduces the possibility of vaporisation or volatilisation with the result that the material which would normally be removed is retained beneath the surface skin and polymerised by the heat of the oven. This is exemplified by sample B, which gave by the normal method of test a result of 322 milligrams per 100 c.c. By taking such a quantity of spirit that the gum obtained did not exceed 10 milligrams and by drying at 130° C. for two hours, a result of 80 milligrams per 100 c.c. was obtained.

In the series where varying quantities of the blends were made up to 25 c.c. with gum free spirit, the gum contents after drying at 130° C. were slightly lower in some cases than those where varying quantities alone were taken. The largest discrepancy here is with the 40 per cent. A–60 per cent. B blend and amounts to 7 milligrams. Nevertheless, by restricting the quantity of spirit to give the requisite amount of gum, the results obtained on blends are more nearly the arithmetic mean of the constituents than any previously obtained.

From the foregoing it will be realised that although gums may be dried to constant weight at practically any temperature, the temperature of drying has a very definite effect on the final result.

The following tables indicate the effect of drying at various temperatures and shows the amounts of time required to attain constant weight :—

TABLE XI.

Temperature of drying.

| 97° C. Weights of gum unadjusted. mg/100 c.c. | 97° C. Weight of gum less than 0·01 gm. mg/100 c.c. | 130° C. Weight of gum less than 0·01 gm. mg/100 c.c. | 150° C. Weight of gum less than 0·01 gm. mg/100 c.c. | 190° C. Weights of gum unadjusted. mg/100 c.c. | 190° C. Weight of gum less than 0·01 gm. mg/100 c.c. |
|---|---|---|---|---|---|
| 1 hr. 104 | — | — | ½ hr. 43 | ¼ hr. 52 | ¼ hr. 42 |
| 2 hrs. 91 | 2 hrs. 60 | 1 hr. 47 | 1 „ 45 | ½ „ 52 | ½ „ 45 |
| 3 „ 82 | 4 „ 61 | 2 hrs. 45 | 1½ hrs. 39 | ¾ „ 55 | ¾ „ 44 |
| 4 „ 86 | 5 „ 54 | 3 „ 45 | 2 „ 39 | 1 „ 51 | 1 „ 45 |
| 5 „ 82 | 6 „ 54 | — | — | 1½ hrs. 53 | 1½ hrs. 43 |

TABLE XII.

| Temperature of drying. | Constant weight attained. | Time required for drying to reach a constant weight. |
|---|---|---|
| 97° C. .. | 54 mg/100 c.c. .. | 4 hours |
| 130° C. .. | 45 „ .. | 2 „ |
| 150° C. .. | 39 „ .. | 1½ „ |
| 190° C. .. | 44 „ .. | ½ hour |

It is considered from the above that the optium conditions for achieving a consistent result with reasonable speed of drying would be at a temperature of 150° C for 1½ hours.

*Standardisation of a Method for Gum Determination.*—With the foregoing results and conclusions in mind, a tentative standard test for the determination of gum in cracked spirits has been drawn up for use in this laboratory as follows :—

*Test for the Gum Content of Cracked Spirit.*—The glass dish to be used for this test shall be hemispherical in shape, 7 cm. in diameter and 3·5 cm. in height; it shall be 20 grammes in weight with a tolerance of ±2 grammes. The dish shall be chemically clean before use, and all handling throughout is to be by metal forceps. Before being used for a test the clean dish shall be placed in a steam oven for not less than 20 minutes, in a desiccator for 20 minutes, and then weighed. It shall then be placed on an actively boiling steam bath fitted with air jets placed vertically over the centre of the holes of the bath at a distance of 4 cm. from the top of the bath. The jets

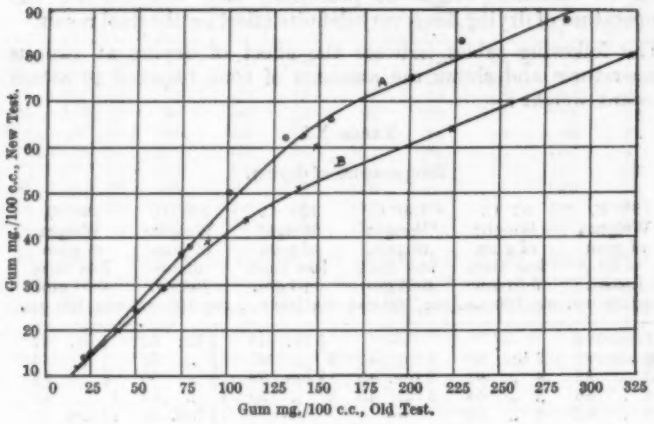



FIG. 5.

COMPARISON OF OLD AND NEW TESTS FOR GUM.

A. Liquid Phase cracked spirit.
B. Vapour Phase cracked spirit.

shall consist of holes 0·036 in. in diameter, each situated in the centre of a diaphragm ($\frac{3}{8}$ in. diameter, $\frac{1}{16}$ in. thick), the air pressure being maintained at the equivalent of 1·25 cm. (0·5 in.) of water. The holes in the steam bath for accommodating the dishes shall be 5 cm. (2 in.) in diameter; 25 c.c. of the sample or blend to be tested shall be measured out by means of a pipette into the previously weighed dish, and the latter with its contents placed on the steam bath and allowed to remain there for 1 hour. If the contents of the dish are not "dry" at the end of this time, the dish shall be left on the steam bath for 15 minutes after the gum is visually dry, or until fuming has ceased. If the actual weight of gum finally obtained exceeds 11 mgs. the test must be repeated,

taking the largest quantity of the sample (in multiples of 5 c.c.) which will give not more than this weight. Conversely a suitable blend can be made, 25 c.c. of which will give approximately 10 mgs. of gum. The blending material shall be a gum-free spirit with a boiling range approximately the same as the material under test. After remaining for 1 hour on the steam bath the dish shall be transferred to a jacketed oven maintained at 150° C. and allowed to remain there for 1½ hours. At the end of this period the dish shall be placed to cool in a desiccator for 20 minutes and finally weighed. The gum content shall be calculated and expressed as mgs. per 100 c.c. (=mg/100 c.c.).

Determinations of gum were carried out under the above conditions on a number of samples of both liquid phase and vapour phase cracked spirit, and the results compared with those obtained by the older method described (evaporation and drying at 100° C. for 1 hour). It was found that the correlation curves of liquid and vapour phase spirits were not the same, and it is evident from the figures given on Table XIII. below and on Fig. 5, that the two types of spirit and their gums react somewhat differently on heat treatment. The two curves (Fig. 5) can be utilised in order to obtain a rough idea of how the results of the new test compare with those of the older method, but it is necessary to know the mode of formation of the spirit in question. The curves cannot be relied upon absolutely as the authors have on occasions met with anomalies when reading from the new test to the old.

TABLE XIII.

| Liquid phase cracked spirit. | | Vapour phase cracked spirit. | |
|---|---|---|---|
| Older test. | New test. | Older test. | New test. |
| mg/100 c.c. | | mg/100 c.c. | |
| 11 | 7 | 17 | 12 |
| 21 | 14 | 41 | 20 |
| 25 | 15 | 64 | 29 |
| 50 | 24 | 89 | 39 |
| 74 | 36 | 110 | 44 |
| 79 | 38 | 139 | 51 |
| 101 | 50 | 148 | 60 |
| 132 | 62 | 223 | 64 |
| 157 | 66 | 322 | 80 |
| 201 | 75 | | |
| 228 | 83 | | |
| 287 | 88 | | |
| 322 | 92 | | |

The authors desire to express their thanks to Dr. F. B. Thole for his many valuable suggestions during the course of this work, and to the Directors of the Anglo-Persian Oil Company, in whose research laboratories this investigation was carried out, for permission to publish this paper.

# REVIEWS.

**Oilfields in the United States.** By Walter A. Van Wiebe. McGraw-Hill Publishing Co., Ltd. London, 1930. 30s. net.

Anyone responsible for teaching the subject of Geology of Petroleum will appreciate the difficulty there has always been in finding some philosophical basis of discussion of the oilfields of the United States. Geographical situation is of little count now that potential regions are fast becoming actualities of oil production, and coalescence of what were once separate fields, the gradual expansion of areas to localities, localities to regions, regions to extensive belts and zones, demands some fundamental scientific classification which the conception of "petrographic province" as such fails entirely to satisfy. The framework adopted by the author is probably the only logical one possible in the circumstances, that of "tectonic classification," the grouping of oilfields, whose relationship is primarily controlled by common structural features. Everyone is familiar with the "Appalachian Geosyncline" as an oil-bearing region, whether he be geologically inclined or not, but its delimitations are hard to define in terms of physical features; similarly, everyone knows the term "Mid-Continent" as applied to a vast oil-producing region, but no one would care to draw a geographical boundary which would satisfy the term and at the same time avoid "straying" into other loosely labelled oil-bearing territories. Thus we are brought to realize that controlling factors, such as the Cincinnati Arch, Eastern and Western Interior Coal Basins, the Ouachita-Amarillo Mountain, the Gulf Embayment, and so on, are the keys by which we may decipher peculiarities and common traits serving at once to group one set of oilfields and differentiate it from another set.

The method is practicable and avoids much of the overlap inevitable to other classifications. The author takes each of his eleven tectonic elements, describes the "setting," and then proceeds to fit in the detailed stratigraphy and local structural incidents, which together concern the occurrence of petroleum. The whole book may be visualized as carrying out this plan, and to this extent the departure from customary description of American oilfields is both novel and welcome. There is little doubt that this book will claim its place in technical literature without much struggle, but to my mind there is something singularly uninspiring about it. It would be so refreshing to pick up a new American textbook on oil geology which contemplated a new outlook, a different perspective, original treatment, and conveyed a new message, to say nothing of illustrations of which one is not altogether weary. Even though geology as such cannot change, ideas and knowledge can at least be made progressive, and in this respect I do not think the author has done himself or his subject the justice which the commendable solidarity of his framework might lead us to anticipate.

H. B. Milner.

**Petroleum Development and Technology, 1930.** *Trans. Amer. Inst. Min. Met. Eng.* New York, 1930. Price $5.

The yearly publication of the Institute devoted to petroleum development and technology is always awaited with interest, not only because it constitutes a contemporary review of progress in the industry, but because among the many papers presented can invariably be found valuable data not available elsewhere. Usually one is rather chary of searching too deeply

the highly embellished volumes which appear as monuments to "congresses," "sessions," "symposia," and so on (with one or two notable exceptions in our country), on the ground that such events are often laden with reiteration and "hot air" discussion, that nothing particularly vital is likely to find expression therein. It would be a mistake to treat the volumes of the Petroleum Division of the Institute in this light manner, though I am convinced that because the volume naturally takes its place in the serial transactions of an Institute devoted ostensibly to "mining and metallurgy," it is far less known and consulted by oil technologists as a whole than is its desert.

Although the papers collected in this, as in previous volumes, cover a wide range of subjects in the technology, there is usually to be noted an underlying theme constituting the prime motif of the congress concerned. In recent years it has been gas-oil ratio, pressure maintenance, rejuvenation of fields, air-gas lift, and so on; this time the sessions at Tulsa and Los Angeles (October, 1929), and subsequently at New York (February, 1930), were concerned with a truly American problem, unit operation, the extent to which oilfields are being developed in any region by one executive. This has been a very keenly debated subject recently, one which is not without its significance in other countries of the world; the advantages of unit operation in lowering cost of production and in increasing efficiency and extraction of oil would seem to be obvious; we have an excellent example of this in Persia. Unrestrained competition among independent interests denies any possibility of conservation of either oil or gas, and waste is inevitable; any policy, be it unitization or some other form of agreement, making for the elimination of extravagant exploitation of an oil-pool, must commend itself to men of vision, and the Institute has done good service in devoting its recent deliberations to this vital matter. For the rest, there are papers on well-spacing, gas-oil ratios, hydraulics of flowing wells, increasing the extraction of oil, valuation methods, oil recovery, cementation, drilling muds, corrosion economics, world production, refining, and petroleum engineering education, in short, a comprehensive and timely review of the current politics of the industry undertaken by men who know their subjects.

H. B. Milner.

Technical Data on Fuel. Second Edition. British National Committee, World Power Conference. Edited by H. M. Spiers. Pp. xiv. + 242. 12s. 6d.

The first edition of this collection of data was published in 1928 at the time of the London Fuel Conference (a Sectional Meeting of the World Power Conference). The Technical Committee, under the chairmanship of Dr. C. H. Lander, Director of Fuel Research, comprises many names of those well known in connection with fuel questions, including members of this Institution, and gives all the weight that such authority can give to the mass of information in this volume.

Much useful material is published for the first time, such, for instance, as the pressure drop in coils, creep data of various alloy steels (additional to other data on alloys and ferrous metals) and the properties of various coal tars.

Seven sections are devoted to more or less general tables, etc., of data of a generally useful character, and five sections more specifically to fuel data.

Such a publication obviously does not enable any detailed review or even criticism to be written. It would be difficult not to find the required data on any point in connection with fuel problems in these pages.

J. S. S. Brame.

INCREASING THE RECOVERY OF PETROLEUM. Wentworth H. Osgood. 2 vols. McGraw-Hill Publishing Co. London, 1930. 50s. net.

Lieut.-Com. Osgood is to be congratulated on the two volumes which he has recently contributed to the Petroleum Technologists' library.

In view of present day knowledge that the greater proportion of the oil in Nature's reservoirs is not recovered by existing practice, the subject, when treated as an economic one, is of vital importance to oil producers.

In the early stages of the industry oil was won without due regard to the scientific principles involved, but this is now, fortunately, a thing of the past. The fact remains, however, that recovery practice, rapidly as it is proceeding on scientific lines, is as yet in its infancy, and methods, unthought of at the present, will be evolved in the future.

The efficient maximum recovery of oil proved by the drill is a problem on which the larger oil organizations are to-day spending considerable sums in research, with consequent reduction in the waste of these valuable assets.

In the first volume of this work the author reviews the conditions under which oil is found in nature and discusses the application of hydraulics to oil recovery. He deals extensively with the utilization of the natural forces involved.

The chapter on the gas factor reviews the literature on this important subject and will be of great use to petroleum engineers. We wish that he had commented on the method of expressing the oil-gas ratio. In certain fields this is taken as the volume of gas to unit volume of oil, *i.e.*, one cub. ft. instead of the usual American practice of expressing it as the volume of gas to one barrel of oil—the former is more scientific and could with advantage be put to general application. He completes the first volume by a useful survey of re-pressuring.

The second volume reviews in a very comprehensive manner all that has been published in recent years on air or gas lift.

As the author states in the preface the book originated as a personal file of items of information and extracts from many writers on this vital problem. There is, therefore, little original matter not hitherto published, but the compilation and editing of this is excellent.

Considerable progress has been made in the science of oil recovery since this book was compiled, but, unfortunately, much of the scientific work undertaken remains hidden in oil companies' archives, especially those companies who are fortunate enough to undertake "unit operation."

Lieut.-Com. Osgood's compilation, therefore, is an up-to-date review of scientific production problems, and is a book which should be in the possession of all petroleum engineers dealing directly or indirectly with these problems.

We would suggest that in the second edition a complete bibliography of the authors and publications quoted or referred to could be added.

The author does not appear to have missed any technical papers or publications of interest, and as a review of all that has been written on the subject it will be of great value for reference. C. A. P. SOUTHWELL.